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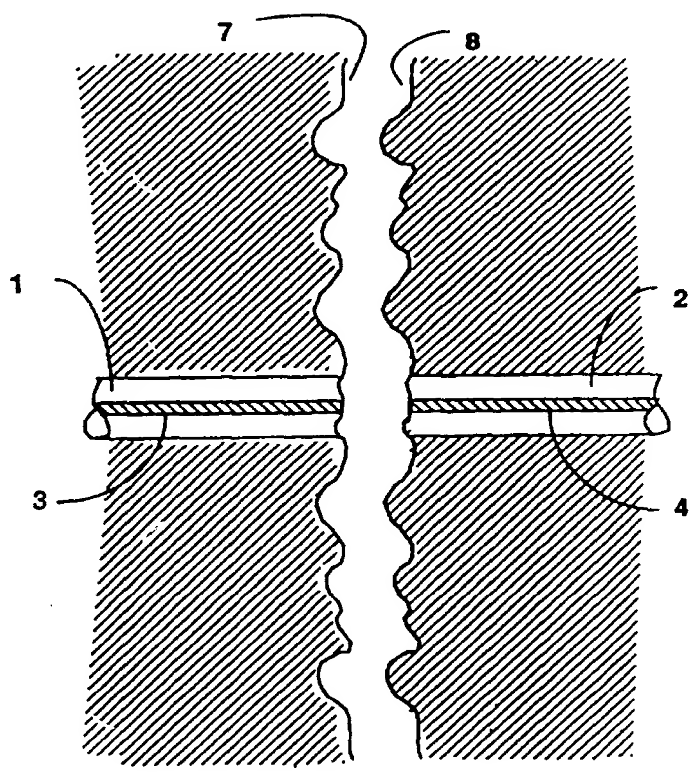
(54) Title: FACE-LOCK INTERCONNECTION MEANS FOR OPTICAL FIBERS AND OTHER OPTICAL COMPONENTS, AND MANUFACTURING METHODS OF THE SAME

(57) Abstract

A novel means for interconnecting optical fibers (1), (2) or waveguide channels is disclosed, in which two matching surface contours are fabricated, one contour (7), (8) on the plane containing the end face of the fiber or the waveguide channel, and the other contour (9), (10) on a surface to which the optical fiber or waveguide channel is to be mated. The matching surface contours are face-locked in a stable and unique position when the two surfaces are brought to each other, thereby positioning the end of the optical fiber or waveguide channel on a pre-determined location on the mating surface. The matched surface contours may be created on the end facet of the optical fiber (1), (2) itself, or on the outwardly-extended surface of the end facet. The same interconnection means may be applied for connecting other optical components such as lenses and light sources. Modular approach is feasible in which a combination of face-lock embodiments are stacked together to align these optical components.



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Description

Face-Lock Interconnection Means for Optical Fibers and Other Optical Components, and Manufacturing Methods of the Same

Technical Field

This invention pertains generally to the field of optical components, and particularly to means for interconnecting optical fibers and other optical components.

Background Art

Optical fibers have been used widely for many applications, most notably for optical fiber communication. In 1980's the optical fiber communication was mostly for linking the telephone central offices. In such an application, one optical fiber carries typically thousands of telephone (voice) channels, and the cost of the fiber optic components such as fiber-to-fiber connector and mechanical splice is not a critical issue. However, as the optical fiber communication is inching toward individual offices and residential area, especially as a part of information superhighway infrastructure construction, the cost of such components become the major issue. Actually this issue is at the present time the most serious stumbling block in constructing the information superhighway infrastructure using optical fibers. The cost should come down by a factor of about ten before optical fibers can be deployed widely.

The cost of optical fiber connectors and mechanical splices are high due to the small size of the optical fiber cross-section. The same is true for mating optical fibers to integrated optic planar channel waveguides. A single-mode fiber, the most-commonly used fiber, has about a 9-micron core surrounded concentrically by about a 125-micron

cladding. When two single-mode fibers, or a single-mode fiber and a waveguide channel, are mated, the cores, or the channels should be aligned within one or two microns in terms of the transverse offset. In order to accomplish such a mating between optical fibers, each of the fibers is inserted in a tubing or plug with about two or three millimeters (1 millimeter = 1,000 microns), and about 125 microns inside diameter (ID). The alignment is typically achieved by aligning the plugs inside another tubing called the sleeve. This requires that the size of the hole or bore of the sleeve be larger than the diameter of the plug by one or two microns, that the hole or bore of the plug be at the center with better than one or two microns, that the size of the bore be larger than the fiber diameter by only one or two microns, that the fiber diameter be 125 microns plus or minus one or two microns, and that the core be located at the center of the fiber within one micron or better tolerance. All these tight dimensional requirements drive up the cost of the optical fiber connection, and to some degree the cost of the optical fibers as well. Connection of an optical fiber to a channel waveguide (such as found in an integrated optic modulator or a planar waveguide coupler) has a very similar technical difficulty, which results in a very high cost. These costs would never be low enough for wide applications so long as all these requirements should be satisfied for optical fiber connections.

Similar technical difficulties exist in connecting other optical components such as laser diodes, light emitting diodes, and lenses. These interconnections are often found in various fiber optic-related packages. For example, a light from a laser diode is coupled to an optical fiber end via a focusing lens. The alignment of these components requires better than one-micron accuracy along the optical axis.

Disclosure of Invention

Accordingly, it is the primary objective of the present invention to devise an alternative approach for mating optical fibers, waveguide channels, light sources, lenses, etc.

It is the ultimate objective of the present invention to lower the interconnection cost for optical interconnections involving optical fibers, integrated optic waveguides, light sources, detectors, lenses, and other related optical components so as to maximize the contribution of the fiber optics to the construction of information superhighway infrastructure.

The basic approach of the present invention for connecting an optical fiber to another optical fiber or any other optical device is to provide a surface contour on the end facet, or on the extension of the end facet, of the optical fiber, and to provide a matched surface contour on the end face, or on the transverse extension of the end face, of the other optical fiber or the optical device. The surface contours of the end faces are designed to be locked in a stable mating position when the two surfaces are brought together. This novel mating mechanism is named "Face-Lock" in this invention disclosure. The surface contours preferably consist of fine features, with the dimensions of the width and the depth of the fine features comparable to that of the optical fibers, so as to have alignment resolution in the order of microns or better.

The formation of the contours on the end faces of an optical fiber may be conveniently achieved first by providing a proper doping distribution across the optical fiber cross-section while manufacturing the fiber, and then preferentially etching the end face using a proper chemical etchant, the etching rate of which depends on the kind and the concentration level of the dopant. In a different approach, the doped regions may be used to guide an ultra-

violet light beam to expose a UV-curable polymer and thus form a face-lock feature at the end of the fiber. Also, photolithographic techniques may be employed to generate surface contours with sub-micron accuracy. Similar manufacturing methods may be applied to integrated optic waveguide end-facets, and other optical devices that require optical interconnections.

A modular approach is possible in the present invention in which a selected combination of face-lock embodiments are stacked together, one on top of the other, to align a number of optical elements.

Brief Description of Drawings

Figure 1 shows schematically two optical fibers in the end-butt alignment positions.

Figure 2 shows schematically the optical fibers of Figure 1 housed in connector plugs in an conventional alignment embodiment.

Figure 3 shows a sectional view of the embodiment of Figure 2 across the U-U' plane.

Figure 4 shows the basic embodiment of the present invention for achieving the alignment of the two optical fibers shown in Figure 1.

Figure 5 shows the front and the side view of one of the optical fibers of Figure 1, the fiber having been modified to have a novel face-lock mating feature on the end face.

Figure 6 shows the two optical fibers of Figure 1 modified to have matched face-lock features.

Figure 7 shows the two optical fibers of Figure 1 modified to have a face-lock feature, and a face-lock insert sandwiched between the two optical fibers.

Figure 8 shows an optical fiber with additional channels with high refractive index outside the central core.

Figure 9 shows schematically a method of fabricating the face-lock feature on the fiber of Figure 8 by exposing an UV-curable polymer through the additional channels.

Figure 10 shows one of the optical fibers of Figure 1 modified to have a concentric tube-like region doped with a certain material that may be preferentially etched chemically.

Figure 11 shows the same as in Figure 10 with the tube-like region preferentially etched chemically so as to form a novel face-lock contour.

Figure 12 shows the optical fiber of Figure 11, its identical mate, and an face-lock insert for mating the two optical fibers.

Figure 13 shows the sectional view of the face-lock insert of Figure 12 across the X-X' plane.

Figure 14 shows the face-lock insert of Figure 12 or 13, modified to have an extended membrane in the X-X' plane.

Figure 15 shows an optical fiber with a face-lock feature that is suitable for direct contour matching with the optical fiber of Figure 11.

Figure 16 shows a conventional optical fiber.

Figure 17 shows the optical fiber of Figure 16 , with the core preferentially etched to form a face-lock contour.

Figure 18 shows the optical fiber of Figure 17, its identical mate, and a face-lock insert in-between.

Figure 19 shows an optical fiber with a protruded face-lock feature that is suitable for direct contour matching with the fiber of Figure 17.

Figure 20 shows the same as in Figure 18, except that the face-lock insert comprises a piece of an optical fiber with matching contours at the both ends.

Figure 21 shows the same as in Figure 18, except that additional light guiding channels are added outside the central core.

Figure 22 shows the sectional views of Figure 21 along the Y-Y' and the Z-Z' planes.

Figure 23 shows the same as in Figure 22, except that keys are added for the orientational alignment.

Figure 24 shows the same as in Figure 3, except that the optical fibers are the ones modified to have a face-lock contour on the end facet so as to be mated through a face-lock insert.

Figure 25 shows the connector plug of Figure 24 modified to have a face-lock insert attached to the front end as an integral part.

Figure 26 shows the face view of the face-lock insert of Figure 25.

Figure 27 shows the same as in Figure 25, except that the face-lock insert is replaced by the one shown in Figure 24 or Figure 26.

Figure 28 shows the same as in Figure 24, except that the face-lock insert is replaced by the one shown in Figure 20.

Figure 29 shows a collar with a face lock contour provided on its face.

Figure 30 shows the face view of Figure 29.

Figure 31 shows the collar of Figure 29, with an optical fiber inserted in the bore.

Figure 32 shows a collar with a face-lock contour that matches with that of Figure 29.

Figure 33 shows the collars of Figure 29 and Figure 32, with optical fibers inserted inside the bores.

Figure 34 shows embodiments slightly modified from the ones shown in Figures 29 and 32.

Figure 35 shows the collars of Figure 34, with optical fibers inserted inside the bores.

Figure 36 shows two identical collars and a face-lock insert in-between.

Figure 37 shows the face view of one of the collars of

Figure 34.

Figure 38 shows the collars of Figure 36 with optical fibers inserted inside the bores.

Figure 39 shows the collars of Figure 38 locked in the mating position via the face-lock insert, thereby aligning the optical fibers.

Figure 40 shows the same plug assembly as in Figure 24 except that the optical fiber is inserted inside a collar with a face-lock feature on its mating face.

Figure 41 shows a novel connector plug assembly in which a face-lock collar is inserted inside the plug bore as an integral part.

Figure 42 shows an optical fiber and an integrated optic channel waveguide to be mated to each other.

Figure 43 shows in more detail the face-lock features on the optical fiber and on the channel waveguide of Figure 42.

Figure 44 shows the same as in Figure 42, except that the fiber's central core and the channel waveguide are accompanied by satellite channels provided for face-locking.

Figure 45 shows in more detail the face-lock features of the satellite channels.

Figure 46 shows an optical fiber with many cores linearly arranged, and with face-lock contours.

Figure 47 shows an array of waveguide channels fabricated on a substrate.

Figure 48 shows the sectional view across Y-Y' of the optical fiber shown in Figure 46, and the plan view of waveguide channels shown in Figure 47, in mating position.

Figure 49 shows the same as in Figure 46, except that two neighboring cores are separated by slits.

Figure 50 shows the same as in Figure 46, except that two neighboring cores are separated by strips of doped regions.

Figure 51 shows the plan view of the optical fiber of

Figure 50.

Figure 52 shows the same as in Figure 50, except that the doped strips have been etched away near the end facets.

Figure 53 shows a partial view of the optical fiber of Figure 51, and a calibrating face-spacer, in which the spacing of the cores is shown to be slightly different from the face-spacer.

Figure 54 shows the optical fiber and the face-spacer of Figure 53 in a locking position, in which the spacing of the cores are calibrated by the face-spacer.

Figure 55 shows a connector plug and an optical fiber with a "core-extension" on its end.

Figure 56 shows the optical fiber of Figure 55 modified to have a face-lock contour on the end-facet.

Figure 57 is the same as shown in Figure 55 except that the optical fiber is the type shown in Figure 56.

Figure 58 shows the same as in Figure 57, except that the optical fiber is removed from the connector plug.

Figure 59 shows a thin-slab with a face-lock features and a through-hole for terminating an optical fiber.

Figure 60 shows the sectional view of Figure 59 across Z-Z'.

Figure 61 shows the same as in Figure 59, except that there are many through-holes for an array of optical fibers.

Figure 62 shows the sectional view of Figure 59 across Z-Z' in which the face-lock feature and the through-hole are fabricated by preferential etching on a (100) silicon wafer.

Figure 63 shows the same as in Figure 62, except that the face-lock feature and the through-hole are fabricated on the opposite sides of the (100) silicon wafer.

Figure 64 shows the masking step in the fabrication process of making the alignment v-groove shown in Figure 62 or 63.

Figure 65 shows the face view of the embodiment shown in Figure 64.

Figure 66 shows the etching step in the fabrication process of making the alignment v-groove shown in Figure 62 or 63.

Figure 67 shows the same as shown in Figure 66, except that the masking layer is stripped off.

Figure 68 indicates that the same process shown in Figures 64 through 67 can be used to make a through-hole as well as the alignment groove.

Figure 69 shows the face view of the embodiment shown in Figure 68.

Figure 70 is the same as shown in Figure 68, except that the etching masks are laid down on the both sides of the silicon wafer so as to realize the embodiment shown in Figure 63.

Figure 71 shows the same as shown in Figure 63, except that more than one through-holes are fabricated.

Figure 72 repeated the face view of the through-hole of Figure 69.

Figure 73 shows one set of three through-holes with slightly varying dimensions.

Figure 74 shows a two-dimensional array of the set of through-holes and corresponding alignment grooves located on the both sides.

Figure 75 shows a matched pair of an alignment groove and an alignment ridge.

Figure 76 shows two recessed alignment grooves and a cylindrical face-lock insert in-between.

Figure 77 shows the sectional view of three alignment grooves of Figure 74.

Figure 78 shows that the same as shown in Figure 77, except that the alignment was shifted by one notch.

Figure 79 shows that four pieces of face-lock embodiments are stacked together, one top of the another, for optical alignment between a light source, a lens, and an optical fiber.

Figure 80 shows the same as shown in Figure 79, except that the path of light from the light source is shown in a schematic manner.

Figure 81 shows schematically the essence of the face-lock mechanism of the present invention.

Figure 82 shows sectional views of one connector part in a switching embodiment of the present invention.

Figure 83 shows a second connector part corresponding to the connector part illustrated in Figure 82.

Figure 84 illustrates one possible mating position of the connector parts shown in Figures 82 and 83.

Figure 85 shows a second possible mating position of the connector parts shown in Figures 82 and 83.

Figure 86 shows a third possible mating position of the connector parts shown in Figures 82 and 83.

Figure 87 shows sectional views of the collar of Figure 32, in which the v-grooves of the collar of Figure 32 are replaced by sets of v-squares.

Figure 88 also shows a sectional view of the collar of Figure 32, in which the v-grooves are replaced by sets of v-squares.

Figure 89 shows a possible mating position of the collar shown in Figure 87.

Figure 90 shows a second possible mating position of the collar shown in Figure 87.

Best Mode for Carrying Out the Invention

Optical interconnection between various optical components such as light sources, optical fibers, lenses, detectors, and interference filters poses a substantial technical difficulty, especially in the fiber optics area. Interconnection becomes one of the economic stumbling blocks as the fiber optics is trying to expand its application toward users' premises. The alignment tolerance is typically less than one or two microns, and this drives up

the interconnection cost beyond economically viable levels for low-end applications such as local area networks. The present invention is trying to resolve this problem. We will start our detailed description using the most prominent example, namely optical fiber-to-fiber connection. Then later we will describe interconnections involving planar channel waveguides, lenses, light sources, etc.

Figure 1 shows in a highly schematic manner two optical fibers (1) and (2) in an end-butt connecting position. The light (depicted as arrows) being guided by the optical fibers is largely contained inside the cores (3) and (4). The region outside the core is called cladding, and it has a lower index of refraction so as to provide an optical barrier or wall around the light-guiding core. The connection or mating is to accomplish the transfer of the light from one optical fiber to the other. When the mating is releasable, it is called demountable connection, or simply connection. Hardware that aids such connection is called an optical fiber connector or simply a connector. When the mating is meant to be permanent, it is usually called a permanent splice or simply a splice.

Figure 2 shows the fiber (1) housed in a connector plug (5), and fiber (2) in another identical plug (6). The plug is typically a cylinder with a hole or bore. Figure 3 shows the sectional view of Figure 2 across the U-U' plane. Let's denote the diameter of the fiber (1) as "F", and that of the core (3) as "C". The diameter of the plug is denoted as "P" and the bore size by "H".

In assembling the optical fiber (1) and the connector plug (5) as shown in Figure 2, the hole of the plug (5) is filled with liquid-form cement material, and the fiber (1) is inserted through the plug hole until its end sticks out of the hole by a few millimeters. After the cement material is solidified, the end of the plug (5) is polished until the fiber (1) and the cement material are flush at the end

facet. The second plug (6) is prepared in the same way. The two plugs (5) and (6) are inserted in a tubing called a sleeve, and are mated in a face-to-face fashion.

The difficulty of mating of two optical fibers as described above, and the resulting high cost of fiber connection, may be understood if the typical dimensions for C, F, H, and P are listed for the most commonly used optical fibers: C=9 microns, F=125 microns, H=(125 + 1 or 2) microns, and P = 3,000 microns = 3 mm. In Figure 1 or Figure 3, the 9-micron (C) cores (3) and (4) should be aligned within one micron in order not to suffer from a substantial light loss in the mating. In order to satisfy such a tight alignment requirement, all the dimensions listed above should be accurate within one micron or so, and the core (3) and the hole of the plug (5) should be concentrically located within one micron or so. Even with such tight tolerances satisfied, the worst-case misalignment can be as large as a few microns as the deviations can add up in an unfavorable manner.

The implication of the conventional mating method and the resulting tight tolerances as described above is quite detrimental. The optical fibers should be drawn within one or two microns from the nominal diameter of 125 microns, meaning that any fibers outside this specification will be rejected. This drives up the fiber cost. The connector plugs and the sleeve should be fabricated with the same resolution. The plug outside diameter P, and the sleeve's hole size, are typically 2,000 to 3,000 microns plus or minus one or two microns. Thus one or two micron tolerance is translated into less than 0.1% of the diameter. This results in high fabrication cost and low yield. In addition polishing of the plug -fiber assembly adds to the overall cost. Today, the material cost for a set of connectors for single-mode fibers is over 50 dollars. Connectorization labor cost itself costs almost as much. In comparison, a

typical connector for electronic coaxial cable is available at two or three dollars at retail stores, and the connectorization procedure is very simple. The high cost of optical fiber interconnection spells a disaster in an effort to use optical fibers in the often-touted national information superhighway.

We notice that the conventional connector and splice are based on alignment of the side walls, namely inside and/or outside of the cylindrical surfaces of the optical fiber, the plug and its bore, and the bore of the sleeve. This element make it necessary to maintain those inner and outer diameters within one or two micron accuracy.

Avoiding these detrimental aspects of the conventional fiber interconnection methods, the connector and splice embodiments of the present invention are designed around the optical fiber end facet, instead of the side walls. The essence of the present invention is depicted in the general term in Figure 4. In Figure 4 are shown four elements: an optical fiber 1 with its end terminated, a first surface 7 residing on the plane coinciding with the end-facet of the optical fiber (1), another optical fiber (2) to be connected to the optical fiber (1), and a second surface (8) residing on the plane coinciding with the end-facet of the optical fiber (2). The first surface (7) has a unique contour on it, while the second surface (8) has another unique contour that may be locked to that of the first surface (7) in a stable position when brought together; the extent of the first surface (7) may be limited to the end facet of the optical fiber (1), or may be extended beyond the end facet of the optical fiber. The optical fibers (1) and (2) are located in pre-determined locations on the first and the second surfaces, (7) and (8), respectively in such a way that, when the two surfaces (7) and (8) are surface-locked into the matching position, the optical fibers (1) and (2) are aligned properly. The present invention as depicted in

Figure 4 will be described below in detail using various examples of possible embodiments.

We will start with Figure 5 showing one simple example of the novel embodiments of the present invention. It shows the front view and the side view: hemispherically-protruded surface contours (9) and (10) are added to the end facet of the optical fiber (1) shown originally in Figure 1. Figure 6 shows the fiber (1) of Figure 5 on the left, along with another fiber (2) on the right with the end facet modified to have recessed counters (11) and (12). These recessed contours (9A) and (10A) match the surface contours (9) and (10) of the fiber (1) on the left. In this novel mating approach, the dimensional requirements are concentrated on the surface contours. All other dimensions shown in Figure 4 do not have to be precise, so long as the hole size H of the plug (5) or (6) is several microns larger than the fiber diameter F, so that the fibers (1) and (2) in Figure 6 are roughly aligned to allow the surface contours (7) and (8) to slip into the recessed contours (9) and (10) when brought together closely.

The rationale for the drastic change in the mating mechanism as described in this invention disclosure is that it costs less to create contours on a surface with micron or sub micron precision, than to make all the diameters of three dimensional sleeve, plugs, and optical fibers with micron or sub micron precision. All the lithographic techniques employed in integrated circuit and semiconductor device manufacturing are basically for creating surface contours with sub micron resolution. Such techniques and others (to be described below) can be used to generate detailed face-locking contours on the end facet of the optical fibers and the plugs.

As a side remark, most of the optical fibers have a circular cross-section with the core at the center. In other words, it has the circular-symmetry or point-symmetry,

which means that the fiber may be rotated about the core without causing any geometrical change. This feature is detrimental in connecting optical fibers that have a polarization-maintaining feature, either by an elliptical core or by stress-induced birefringence. It is worthwhile to note that the surface contours as shown in Figure 5 or 6 are asymmetric, and provide the orientation to the otherwise circularly-symmetric fiber. By mating optical fibers utilizing such a novel surface contour, one can splice or connect polarization preserving fibers with perfect orientational alignment. This is a side, but significant benefit of the present invention.

Figure 7 shows a slight modification of the face-locking embodiment of Figure 6. The fibers (1) and (2) both have recessed contours (9) through (12), and face-lock inserts (13) and (14) are provided to mate the two fibers (1) and (2).

One way to fabricate the protruded contour shown in Figures 5 or 6 is to provide core-like channels (15) and (16) inside the fiber (1) (see Figure 8), in such a way that the channels (15) and (16) have an index of refraction higher than the surrounding cladding. Then the end of the fiber (1) is immersed in an UV-curable polymer (18), as shown schematically in Figure 9, and a UV light (17) is coupled into the channels (15) and (16). By controlling the total amount of the UV energy, spherical contours (9) and (10) may be fabricated on the fiber surface, as indicated in Figure 9.

Another approach to make a surface contour is to draw an optical fiber in which the core-like channels (15) and (16) of Figure 8 are replaced by hollow holes throughout the length of the fiber. The recess provided by the hollow holes may be mated with the protruded contours (7) and (8) of Figure 5.

Another approach is by a selective chemical etching.

The core-like channels (15) and (16) of Figure 8 may be made by doping certain materials while making the fiber preform. When the fiber end surface is etched in a certain chemical, the etching rate at a particular spot usually depends heavily on the kind of doping material and its doping level. For example, in the commercial optical fibers, the core (1) is doped with germanium, and thus etches in hydrofluoric (HF) acid or the like substantially faster than the cladding which is typically a pure fused silica (SiO_2) with no doping. The higher the doping level, the faster is the etching rate. Actually, graded doping results in a graded contour. In general regions with different dopants and different doping levels etch differently in different etchants.

In Figure 10 is shown a front and a side view of an optical fiber (1) which is doped with a certain dopant inside the tube-like region (19) outside the core (3). By etching the fiber end face with a proper etchant that etches mainly the doping region (19), recessed contour (20) may be obtained on the concentric tube-like region (19), as schematically depicted in Figure 11. One pair of fibers with such recessed contours (20) and (22) may be mated, as shown in Figure 12, using a donut-shaped face-locking insert (23). The sectional face-view of the face-locking insert (23) is shown in Figure 13. The outer boundary of the insert (22) may be extended by a thin membrane (24) as shown in Figure 14 so as to make the handling easier (remember that the typical size of the face-lock insert (23) would be less than 0.12 mm).

The doping material and its doping level of the tube-like region (19) and the surrounding elements of Figure 10 may be altered to result in a protruded contour (25) as shown in Figure 15.

Existing optical fibers may be suitable as is for fabricating a face-locking contour. As an example, Figure

16 shows schematically a multimode fiber (26) with the diameter of the core (27) about 50 microns and the cladding diameter 125 microns, or 50/125 microns. Also available commercially are fibers with core/cladding diameters 62.5/125 and 100/140 microns. The cores of these fibers have a so-called graded-index profile, and the germanium doping level is accordingly graded as the doping level is proportional to the index of refraction. When immersed in a HF acid for one or two minutes, the front face is etched differentially to have a recessed face contour (28) as shown in Figure 17. Two fibers (26) and (29) prepared as such may be mated via a face-lock insert (32), as depicted in Figure 18. With a modified doping, the fiber (29) may have a protruded face contour (33) as shown in Figure 19.

Figure 20 shows another possible embodiment of a face-lock insert (34), that is made of a same optical fiber as the connecting fibers (26) and (29). The two ends have two protruded surface contours (36) and (37) for mating. The length of the face-lock insert (34) may be a few millimeters or longer.

One interesting modification of the embodiment of Figure 18 is shown in Figure 21, in which additional channels (38) through (41) are added in the outskirt. Figure 22 shows the sectional view along Y-Y'. There are at least three ways to use these channels: 1) the central channels (27) and (30) may be used for light-guiding, potentially preserving the polarization, with the outside channels used for face-lock mating; 2) the central channels (27) and (30) may be used only as face-lock means, and the outside channels (38) through (41) are used for guiding optical signals; or 3) one or two of the channels (38) through (41) may be etched into a face-locking contour, and used for an orientation-locking key. Alternatively, one or more longitudinal slots (42) and (43) may be provided on the outer surface of the optical fiber, as shown in Figure 23,

to provide means to define the orientation of the optical fiber. The slots or keys (42) and (43) may be fabricated by the same technique that is used for fabricating the face-locking contours, namely doping the key regions (42) and (43) with preferentially-etchable material, followed by chemical etching.

Above, we described a few examples of the novel optical fiber embodiments designed to be suitable for the face-lock connection. We also described some examples of manufacturing methods of the embodiments. Optical fibers are hair-thin and flimsy, and thus difficult to handle. Accordingly, in order to make the connection and splice manageable, each fiber is usually housed in a tubing or plug (5) or (6), as depicted in Figure 2. Incorporation of such housing with the novel face-lock connection embodiments will be described now, using the embodiment shown in Figure 17 as an example.

In the conventional connectors, the fibers are glued inside the plug bore, and then its end surface is polished. In this invention disclosure, the labor-intensive polishing procedure may be omitted, as will be clarified below.

The size of an optical fiber is typically 0.125 mm, while the size of a plug is 2 to 3 mm. The details of the surface contours for the face-lock connection described in this invention disclosure would have dimensions preferably less than 0.1 mm so as to possess precision alignment capability. If the hair-size fiber to be mated is rigidly held on a relatively massive plug, the face contours as described above would be too small and fragile to align the whole plug-fiber assembly against another plug-fiber assembly. Accordingly, it may be desirable to leave the end of the fiber (26) unattached and free inside a plug bore, as shown in Figure 24. The fiber (26) could be anchored only at the rear end using a glue (44) as shown. Then the flimsy fiber (26) is free to move around until the surface contour

(28) is locked into the matching contour of a face-lock insert (32).

The face-lock insert (32) may be extended by a thin membrane (45) for easier handling, and may be attached to one of the mating plugs (5) as shown in Figure 25 to become a part of the connector plug. The face view of the insert (32) is shown in Figure 26. The procedure for fiber connection with such a plug-insert assembly is shown in Figure 27: the modified fiber (26) inserted into the connector plug (5) until the face contour of the fiber (26) is properly seated against the matching contour of the insert (32). Then a glue (44) is added at the rear end to keep the fiber in place inside the plug (5). Then another fiber (29) is inserted into another plug (6). A gross alignment (within 10 to 100 microns, depending on the size of the contour details) of the plugs (5) and (6) will be followed by the fine and final alignment via the surface-locking mechanism. When the both plugs (5) and (6) happen to have the insert (45), one of the two inserts may be scraped off.

Figure 28 shows the same as in Figure 24, except that the face-lock insert is replaced by the one shown in Figure 20.

Above, face-lock features were shown to be on the end facet of optical fibers themselves. Such embodiments would be preferred since the contours may be built in with sub micron or micron precision during preform fabrication and fiber drawing, and also since any additional parts are not needed for the final fiber alignment, possibly except for the face-lock insert. However, in some cases it may not be possible to utilize the surface contours of the fiber end facets. First of all, there are a great amount of fibers already laid down and in use, and they do not have such contours. In order to accommodate such cases, a collar (47) as shown in Figure 29 may be used. Its side or face view is

shown in Figure 30. The collar (47) may be called a plug and may be able to function as a plug. However, as will be explained below, it may be preferable to make the collar (29) much thinner (such as 0.2 or 0.3 mm in outside diameter) than the conventional plug (2 or 3 mm), even though it can be as thick as plugs. Thus to maintain the generality, it will be called a collar. The collar (47) is to go over an optical fiber (50), as shown in Figure 31. The collar (47) has a face-lock feature (48) on the end face, as shown in Figure 29. In Figure 29 or 30, the face contour consists of a concentric ring groove (48), but this is merely an example, and some other features will work as well. Figure 32 shows a matching collar (51), and Figure 33 shows the resulting alignment of optical fibers (50) and (52) via the matched set of collars (47) and (51). The size of the hole (49)inside the collar (47) in Figure 29 should be larger than the optical fiber by only one or two microns if the alignment accuracy is to be achieved with such a resolution. This is definitely a drawback as compared to the embodiments shown above in Figure 5 through Figure 28. However, the situation is still substantially better than with the existing connecting method in that, in the conventional connection, the inside diameter and the outside diameter of the plug and the inside diameter of the sleeve should be made with one or two micron tolerance, while in the novel embodiment of Figure 31, such a dimensional tolerance is demanded only on the inside diameter (49) of the collar (47). It is easier to make the bore size precisely when the bulk dimension is smaller. Accordingly, it would be preferable to make the outside diameter of the collar (47) small, such as 0.2 or 0.3 mm. Also, thin collars may be aligned by fine surface contours. Bulky collars will require larger size surface contours.

Figure 34 shows a pair of face-lock collars (53) and (54) with a slight modification from those shown in Figure

33. Figure 35 shows the same with mating fibers (50) and (52) mounted inside the collars (53) and (54).

Figure 36 shows a slight variation of the collar concept, in which collars (55) and (56) are designed to be mated through a face-lock insert (57). The face view of the collar (55) is shown in Figure 37. The face contour features a groove (58) or (59), and a step (60) or (61). As shown in Figure 38 and Figure 39, the steps (60) and (61) accommodate the thickness of the face-lock insert (57), allowing the end facets of the optical fibers (62) and (63) the physical contact without a gap in-between.

Figure 40 shows the same as in Figure 24, except that the optical fiber (62) (outlined with heavier lines) is inserted in a collar which has a face-lock feature on its end surface. It would be desirable to anchor the collar only at the rear (64) so as to keep its end free.

Figure 41 shows the plug assembly shown in Figure 40, minus the optical fiber (62). Such a plug assembly may be sold as a commercial product. The only thing a customer has to do is to cleave a fiber, insert into the collar (52) until the fiber end is flush with the collar end, and secure the fiber in position. The resulting assembly will be as shown in Figure 40.

Collars and the face-lock contours may be manufactured in the same ways as described for the optical fibers and as illustrated in Figures 8 through 23. As an example, an optical fiber preform with its doping profiles modified as shown in Figure 8 or 11 may be drawn to the shape of collar. The surface contours may be fabricated by a UV-exposure as shown in Figure 9, or by a selective etching as described earlier. The wall thickness of the collars is preferably thin, such as 0.05 to 0.5 mm, so as to remain thin and flimsy, which is a desirable characteristics for a high-resolution face-locking. However it would be possible to make the collar much bulkier, and still align them

satisfactorily using the face-lock mechanism. In this case the sleeve inner diameter and the plug outer diameter should be closer so as to achieve very good fit even before the face-lock mechanism makes the contribution to the final high resolution alignment. In this case the connection gets less contribution from the face-locking as compared to the case with a flimsy collar or bare fiber.

It is worth noting that only one mating party has to be thin and flimsy in order to benefit to the maximum from the face-lock mechanism. For example, the face-lock insert (32) and fiber (26) in Figure 27 may be rigidly held so long as the fiber (29) is flimsy.

One important class of optical components is channel waveguides. Such channel waveguides are found in laser diodes, electro-optic modulators and switches, integrated optic couplers, etc. Connection between the channels of such components and the cores of optical fibers need dramatic cost reduction. Below, the novel face-lock feature will be applied to simplify these connections.

An optical fiber such as shown in Figure 17 may be mated to a channel waveguide (65) fabricated on a substrate (66), as shown in Figure 42. The detailed sectional views are shown in Figure 43, in which the face contours (28) and (67) are depicted. A good index-matching fluid would be necessary to reduce the reflection loss at the boundaries of the face-lock features. In order to avoid modifying the fiber core (27) and the channel waveguide (65), satellite channels (68) and (69) may be added as shown in Figure 44. A detailed view Figure 45 shows the face-lock elements (72) through (75). Even though an integrated optic channel waveguide is shown here as an example, the application of the novel face-lock mechanism is practically unlimited: laser diode channel, graded-index rod lens (Selfoc is another trade name), an optical window, and any other objects to which optical fibers are aligned to can utilize

the novel feature of the face-locking.

An optical fiber with linearly-arranged cores has been disclosed in some prior arts such as T900,002. In principle, such a fiber should be more widely used since many optical waveguide devices have a linearly-arranged channels. However, direct mating between the linear array of the cores and that of channels requires about one-micron alignment accuracy. In order to satisfy such an alignment accuracy, the novel surface contour features (76) and (77) are added to the linear array of cores (78) through (82) of an optical fiber (83), as shown schematically in Figure 46. Figure 47 shows the counterpart channels (84) through (88) on a substrate (89). Also shown are two channels (90) and (91) for fabricating protruded contours (92) and (93) as shown in Figure 48, which shows the sectional plan view of the fiber (83) along the Y-Y' plane, and the plan view of the channel waveguide device (89). The mating through the recessed face-lock contours at the fiber channels (76) and (77) and protruded contours at the end of channels (90) and (91) are clearly depicted in Figure 48.

One practical difficulty in achieving a satisfactory mating as shown in Figure 48 is the exact positioning of the fiber cores (78) through (82). When drawing such an optical fiber, the core positions could vary by a few microns or more from the core at one end to that at the opposite end. This will make the connection loss unacceptably high for single-mode cores and channels. Most of the fibers and the waveguide devices (such as laser diodes and integrated optic devices) are of single-mode. In order to solve this problem, the front end of the optical fiber (83) is slit into pieces as schematically shown in Figure 49, in which spacings (92) through (97) are created between each neighboring cores in a regular manner. One way to create such slits (92) through (97) is to dope the fiber (83) along the regions (98) through (103) to be slit (Figure 50, and

its plan view Figure 51), and then selectively etch away using a proper etchant. The result of the etching is shown in Figure 52, which shows that only the front parts are slit. Once the slits are made, the spacing between the cores may be corrected to the right value. For example, let's assume that the spacing "S" between the two slits (93) and (94) is different from the standard, calibrated spacing "T" between teeth (105), (106) and (107) of a space-lock spacer (104), as depicted schematically in Figure 53. By inserting the space-lock spacer (104) into the slits, as shown in Figure 54, the spacing between the fiber cores (78) and (79) and also that between (79) and (80) can be forcefully corrected to the correct value "T".

Another interesting embodiment of the present invention is related to the U.S. Patent 5,287,424, and a patent application 08/155,553. Figure 55 shows an embodiment disclosed in the pending patent application, in which an optical fiber (109) with a core (110) is positioned inside a tubing (111). Then a UV light is coupled into the fiber core (110) to expose a UV-curable polymer at the output end of the optical fiber (109) so as to create a solid-form core-extension (112). One desirable feature of this core-extension (112) is to be able to pull out the optical fiber (109) and insert another optical fiber in the same location. In doing so there is a concern that the new fiber would not be aligned to the core-extension (112) as perfectly as the original fiber (109) has been. In order to remedy this problem with the "demountable core-extension", the face-lock mating mechanism may be applied between the optical fiber (109) and the core-extension (112). This can be done by creating a face-lock feature on the optical fiber and on the core-extension. One example is shown schematically in Figure 56 in which the optical fiber (109) is shown to have a recessed feature (113) at the end of the core (110). The core-extension made with the modified fiber is shown in

Figure 57. When the optical fiber (109) in Figure 57 is pulled out, the remaining core-extension looks as shown in Figure 58. Then any other optical fiber with a recessed contour as shown in Figure 56 at its end can be mated with the core-extension (112) of Figure 58 utilizing the novel face-lock mechanism.

Another important embodiment of the present invention is shown in Figure 59, in which a thin-slab has face-lock feature (115) (see Figure 60 for its sectional view across Z-Z': the detailed shapes of the grooves and the through-hole can be different from shown) and a through-hole (116) through which an optical fiber (117) is terminated at the surface of the thin-slab (114). The alignment of the optical fiber in mating depends on the precise registration of the through-hole (116) with respect to the surface-lock feature (115). The size of the through-hole (116) should be very close to the diameter of the optical fiber (117). This is a technical challenge by itself. However, it will be easier and cheaper to achieve such dimensional control on a planar thin-slab as shown in Figure 59, when compared to the conventional approach as sketched in Figures 2 and 3.

Once the embodiment as shown in Figure 59 can be fabricated, it is straightforward to extend the embodiment and the fabrication technique to a multi-fiber array embodiment as shown in Figure 61, in which an array of optical fibers (118) are terminated on a thin-slab (119). This array capability is another powerful advantage of the present invention compared to the conventional plug-sleeve approach which cannot be readily extended to an array embodiment.

One manufacturing method for making the embodiments shown in Figures 59 and 61 will be now described. The fabrication is based on the well-known preferential etching of a silicon wafer with either (100) or (110) facet. For example, on a (100) silicon wafer, v-grooves can be

fabricated in which the side walls of the v-groove have a definite angle with respect to the surface regardless of the groove size. Utilizing the technique, a v-groove (120) and through-holes (121) and (122) as shown in Figures 62 and 63, respectively, can be fabricated on the surfaces of (100) silicon wafer 123, realizing the embodiment shown in Figure 59. The detailed fabrication steps are as follows: as indicated in Figure 64, a mask layer (124) is patterned on one side and another layer (125) on the other side (this second mask is to prevent etching of the back side) on the silicon wafer using photolithography technique, which has sub-micron resolution in positioning a desired pattern on a pre-determined position. The face view of the section shown in Figure 64 is sketched in Figure 65. Then the wafer (123) is immersed in an etchant that etches the wafer in (100) direction much faster than in (111) direction (by a factor of about 500 to 1,000). The etchant etches the silicon . material into the (100) direction, that is in the direction perpendicular to the wafer surface. The side-walls inside the v-groove (120) shown in Figure 66 are the hard-to-etch facets, namely the (111) facets. Accordingly, the depth of the V-groove depends solely on the width W of the opening of the mask (124). The masks (124) and (125) are stripped off when the etching is completed. The mask layer (124) may be modified as shown in Figure 68 to fabricate two V-grooves (120) and (121). The face view of the section shown in Figure 68 is shown in Figure 69, which indicates that the larger v-section (121) is a tapered square hole with four (111) side walls. This square groove (121) is actually too large to remain within the wafer body (123), as indicated in Figure 68, and thus punch through the wafer, forming a through-hole (121) as desired (see Figure 62). Again, the angle of the side walls are universally the same as it is defined by the (111) facets of the silicon. Accordingly, if the size of the hole W2 and the wafer thickness T are known,

the value for the mask opening W3 can be calculated. The separation S between the V-groove (120) and the through-hole (121) may be replicated with better than 0.5 micron accuracy.

Since the optical fiber (117) is entering from the left side of the through-hole as shown in Figure 59 in our example, it would be convenient to have the through-hole tapered out to the left side of the wafer, as shown in Figure 63. This can be realized by modifying the mask layer (125) on the left-side as shown in Figure 70, in which etching is done on the both sides of the wafer (123). The separation S can be precisely registered by using a mask-aligner that uses infrared light with see-through capability, which allows viewing simultaneously the both sides of the wafer during the mask pattern registration before exposure. The mask layer (124) in Figure 70 may be made of a transparent, thin-film dielectric material such as glass. It does not have to be removed since it may work as a window for optical fiber being inserted in the through-hole (122). The window may be one or two microns thick. Figure 71 shows a straightforward extension of the embodiment and the technique described in Figure 64 through 70 to an array form, in which two through-holes (126) and (127) are prepared in the same manner for aligning two optical fibers (128) and (129). When the window (124) described in Figure 70 remains in embodiment shown in Figure 71, the end facet of the optical fibers (128) or (129) may be glued to the window.

When the through-hole (121) or (122) in Figure 69 or 70 are fabricated, the hole clearance W2 should be very close to the diameter of the optical fiber for precision fiber alignment. The through-hole (121) of Figure 69 is shown separately in Figure 72. For a given value W3, the value for W2 could vary slightly due to the variation of the thickness T of wafer (123) and undercut of the masked edges

by the etchant. For example, the hole clearance W2 could turn out to be anywhere between 124 and 130 microns while the optical fiber diameter itself can vary between 123 to 127 microns. In the worst case the hole size W2 could be larger than an optical fiber by seven microns, or the hole size W2 could be smaller than the fiber diameter. In order to accommodate this variation in the hole size and the fiber diameter, a number of through-holes with varying dimensions can be fabricated, as depicted in Figure 73, which shows three through-holes (130), (131), and (132), which have three different sizes of mask openings W3, W3', and W3", and three corresponding sizes of the through-holes W2, W2' and W2" (as examples, these three values could be 127, 125 and 123 microns, respectively). One of these three through-holes would match to a given optical fiber better than the other holes. The number of holes may be more than three. The resulting embodiment is shown in Figure 74, which is a variation of the surface layout shown in Figure 61: each of the through-holes in Figure 61 is replaced by three through-holes in Figure 74. There are also three sets of the face-lock grooves (133), (134) and (135). The face-lock grooves are used to align two connecting embodiments as shown in Figure 74. The matching grooves may be designed as shown in Figure 75 (a recess (120A) and a protrusion (120B)), or Figure 76 (recessed grooves (120A) and (120C) with a face-lock insert (137)). In either case, the selection of one through-hole out of the three possibilities ((130), (131), or (132) in Figure 74) can be achieved by selecting the corresponding v-groove among the three possible sets, namely (133), (134), or (135). The resulting alignments are shown in Figures 77 and 78 as two possible examples.

Figure 75 shows a matched pair of an alignment groove (120A) and an alignment ridge (120B). Each of the embodiments (123A) and (123B) represent the face-lock surface shown in Figure 59, 61, or 74. As indicated, the

alignment ridge (120B) may be fabricated by etching V-grooves on the both sides of the ridge (120B) on the silicon surface.

Figure 76 shows two recessed alignment grooves (120A) and (120C) and a cylindrical face-lock insert (137) in-between that facilitates the face-locking.

Figure 77 shows a matched pair of the three alignment grooves as shown in Figure 74, (133A) through (135A), and (133B) through (135B). Each set of these grooves are supposed to belong to a face-locking surface as shown in Figure 74. By selecting the grooves to lock via a face-lock insert (137), one may lock the two surfaces either as shown in Figure 77 or Figure 78. In turn, this will determine which through-holes are being used among the three choices, (130) through (132), in Figure 74.

Figure 79 shows that the face-lock embodiment of the present invention can be extended to align other optical components such as a light source (138) and a lens (139). It shows a modular approach, in which a number of face-lock embodiments (123), (140), (141), and (142) are prepared separately and assembled together using the self-alignment mechanism of the face-lock features (120A) and (124B), and the counterparts in the rest of the stack. Photolithography ensures that the optical axis is at the center within one-micron tolerance. The pre-determined thickness of the individual face-lock embodiments (123), (140), (141), and (142)ensures that the distances between the optical components, (128), (139), (138), are accurate. Figure 80 shows that a light (143) is emerging from the light source (138) to be focused by the lens (139) into the fiber core (144). The light source (138) may be a light emitting diode (LED) or surface emitting laser diode (that are energized by a voltage V as shown in Figure 80), or a light delivered to the spot 138 by a set of reflectors or/and deflectors. Micro-machined silicon and other crystal (GaAs or InP)

wafers would preferred materials for such modular face-lock embodiments, since, as described above in detail, the registration of the face-lock features and through-holes can be fabricated with better than one-micron accuracy on these wafers using the standard integrated circuit lithography technology.

Even though the face-lock surface contours (120A), (120B) and the like reside on the surfaces that are mutually parallel in Figure 79, they may be, by a simple extension, provided on other planes, such as the one perpendicular to the face-lock surfaces shown in Figure 79.

(Figures 62, 63, 68, 69, 70, 71, 72, 73, 74, 79 and 80 contain an important and distinct teaching that a through-hole may be tailor-fabricated with better than one or two micron accuracy to terminate and align an optical fiber, or other optical components such as a lens, on a wafer with a preferential etching characteristics. Figures 73 and 74 also teach a method how to prepare a set of through-holes with incrementally varying hole dimensions. Even though these embodiments and teachings are described in this invention, they are not part of the face-lock mechanism or features, which are the main subject of the present invention. Accordingly these embodiments and teachings related to the through-holes will be prepared separately as a divisional patent application of the present (parent) patent application.)

It would be almost impossible to describe all the possible variations that utilize the basic teaching of the present invention. Accordingly, it would be useful to conclude the detailed description by clarifying again the essence of the teaching of this invention using an optical fiber and a lens. Referring to Figure 81, a typical embodiment of the present invention comprises three elements: an optical fiber (145) with its end terminated, a first surface (146) residing on the plane coinciding with

the end-facet of the optical fiber (145), and a second surface (147), containing a lens (148), to be mated with the first surface (146). The first surface (146) has an unique contour on it, while the second surface (147) has another unique contour that may be locked with that of the first surface (146) in a stable position when brought together. The first surface (146) may be limited to the end facet of the optical fiber (138), or that plus a surface extending beyond, such as into the end face of a collar or the (100) surface of a silicon wafer.

The concept of choosing among the multiple grooves 133,134, and 137 in Figure 74 through Figure 77 may be slightly modified to realize an optical switching embodiment. A number of optical components (through-holes 168 through 173 for accommodating optical fibers 174 through 179 in this example), and a number of V-grooves 180 through 186 for face-lock positioning are fabricated on one connector part 187 as shown in Figure 82. Side and front sectional views along the various axes indicated are shown. The other connector part 188, schematically illustrated in Figure 83 using heavy lines, shows an optical component (a through-hole 189 for a fiber 190 in this example) and V-grooves 191, 192, and 193. Figure 84 shows one possible mating position between the two connector parts 187 and 188, whereby the fiber 190 is aligned to the fiber 177. Figure 85 shows another possible mating position, in which the fiber 190 is aligned to the fiber 174. Figure 86 shows yet another possible mating position, in which the fiber 190 is connected to the fiber 175. In this way, one can select different mating positions among periodically-located face-lock features, accomplishing an optical switching from one fiber to another. A mechanical fiber optic switch can be manufactured by mechanizing the switching described herein.

The face-lock V-grooves of Figure 32 and Figure 33 may be replaced by sets of V-squares 194 and 195, as shown in

Figure 87, and by sets of V-squares 203 and 204, as shown in Figure 88. Matching the fiber 202 to one of the fibers among 196 through 201 can be accomplished in the same fashion, as depicted in Figures 89 through 90.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

Claims

1. An optical interconnection means comprising;
an optical component;
a first face-locking surface;
and a second face-locking surface;
wherein the optical component is located at a pre-determined location on the first face-locking surface, and the first face-locking surface has a first type of surface contour; and the second face-locking surface has the second type of surface contour that matches to the first type of contour so as to be locked in position to the first type of surface contour when pressed against the first face-locking surface in face-to-face fashion, whereby a proper positioning of the optical component is achieved through the locking of the two face-locking surfaces.

2. The invention according to claim 1 wherein the optical component is an optical channel waveguide.

3. The invention according to claim 1 wherein the optical component is a lens.

4. The invention according to claim 1 wherein the optical component is a light source.

5. The invention according to claim 1 wherein the optical component is an interference filter.

6. The invention according to claim 1 wherein the optical component is optically transparent.

7. The invention according to claim 1 wherein the first locking surface is planar, and the first type of surface contour includes a lithographically generated

pattern.

8. The invention according to claim 7 wherein the first locking surface is made of a silicon crystal wafer.

9. The invention according to claim 8 wherein the silicon wafer is (100) type that allows a preferential V-groove etching.

10. The invention according to claim 9 wherein the dimension of the V-grooves are chosen in such a way that a cylindrical object may be inserted along the V-groove for aiding alignment by the surface locking.

11. The invention according to claim 1 wherein the optical component is an optical fiber.

12. The invention according to claim 2 wherein the end facet of the optical fiber resides on the first face-locking surface.

13. The invention according to claim 12 wherein the first face-locking surface is limited to the end facet of the optical fiber.

14. The invention according to claim 12 wherein the second face-locking surface resides on a surface of a face-lock insert that is insertable between the optical fiber and another optical component.

15. The invention according to claim 14 wherein the face-lock insert is a molded part.

16. The invention according to claim 14 wherein the face-lock insert is made by photolithographic techniques.

17. The invention according to claim 11 wherein the second face-locking surface includes the end facet of another optical fiber.

18. The invention according to claim 11 wherein the first face-locking surface includes the end-facet of a collar designed to slip over the optical fiber with a tight fit.

19. The invention according to claim 18 wherein the outside dimension of the collar is less than 0.5 mm.

20. The invention according to claim 11 wherein the optical fiber and the first face-locking surface resides inside the bore of a connector plug.

21. The invention according to claim 18 wherein the collar resides inside the bore of a connector plug.

22. The invention according to claim 20 wherein the end of the optical fiber is free to move inside the hole of the connector plug.

23. The invention according to claim 21 wherein the end of the collar is free to move inside the hole of the connector plug.

24. The invention according to claim 11 wherein the first type of contour is made of a photo-reactive material the characteristics of which is altered by a light exposure.

25. The invention according to claim 24 wherein the photo-reactive material is an UV-curable polymer.

26. The invention according to claim 24 wherein the

photo-reactive material is a photoresist material.

27. The invention according to claim 11 wherein the first type of contour is according to the distribution of a dopant that is embedded in the first face-locking surface.

28. The invention according to claim 27 wherein the first type contour comprises a pattern located outside the central core region of the optical fiber.

29. The invention according to claim 28 wherein the pattern consists of a concentric ring.

30. The invention according to claim 28 wherein the optical fiber has a plurality of light-guiding cores.

31. The invention according to claim 11 wherein the first type contour comprises patterns that is non-concentric and circularly asymmetric with respect to the center of the optical fiber so as to provide the orientation to the cross-section of the optical fiber.

32. The invention according to claim 31 wherein the optical fiber is designed to preserve the polarization of guided light.

33. The invention according to the claim 11 wherein the first type contour comprises a pattern located at the center of the optical fiber.

34. The invention according to claim 33 wherein a plurality of cores are located around the pattern.

35. The invention according to claim 33 wherein a key is added to the optical fiber to identify the proper

orientation of the optical fiber.

36. The invention according to claim 11 wherein the second type of contour is according to the distribution of a dopant that is embedded in the second face-locking surface.

37. A method of manufacturing the contours as defined in claim 27 and claim 36, wherein contours are formed by etching the face-locking surfaces with an etchant, in which the local etching rate depends on the distribution of the doping level on the face-locking surfaces.

38. The invention according to claim 1 wherein the face-locking surface features of the first face-locking surface and the second face-locking surface have mutually matched periodic patterns so that the first face-locking surface and the second face-locking surface can be face-locked at many different positions, thus realizing an optical switching capability.

39. The invention according to claim 38, wherein the matched periodic patterns comprise a set of V-grooves.

40. The invention according to claim 38, wherein the matched periodic patterns comprise a set of V-squares.

41. The invention according to claim 38, wherein the matched periodic patterns form a one-dimensional array.

42. The invention according to claim 38, wherein the matched periodic patterns form a two-dimensional array.

43. The invention according to claim 38, wherein there is a through-hole for an optical fiber in each period of the matched periodic patterns, so as to realize optical fiber

switching capability.

44. The invention according to claim 38, wherein the switching from one mating position to another is performed on command by a mechanized means so as to realize a mechanical optical switch.

45. An arrayed optical interconnection means comprising:

an array of a first optical component;

a first face-locking surface;

an array of a second optical component; and

a second face-locking surface;

wherein the array of the first optical component is located on the first face-locking surface, and the first face-locking surface has a first type of surface feature, and the first type of surface feature has a unique positional relationship with respect to the array of the first optical component; and the array of the second optical component is located on the second face-locking surface, and the second face-locking surface has a second type of surface feature that matches to the first type of surface feature so as to be locked in position to the first type of surface feature when pressed against the first face-locking surface in a face-to-face fashion, and the second type of surface feature has the same unique positional relationship with respect to the array of the second optical component; whereas precise optical alignment between the array of the first optical component and the array of the second optical component is achieved through the face-locking of the two surface features and their unique positional relationship with respect to the array of the first and second optical components.

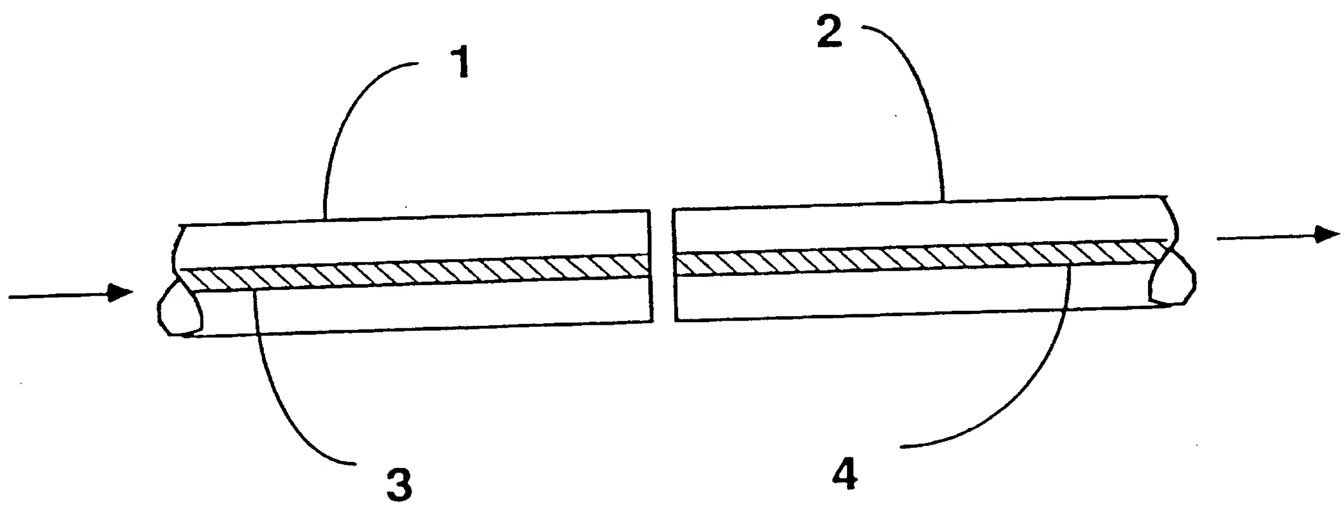

FIG. 1

S.K.Sheem

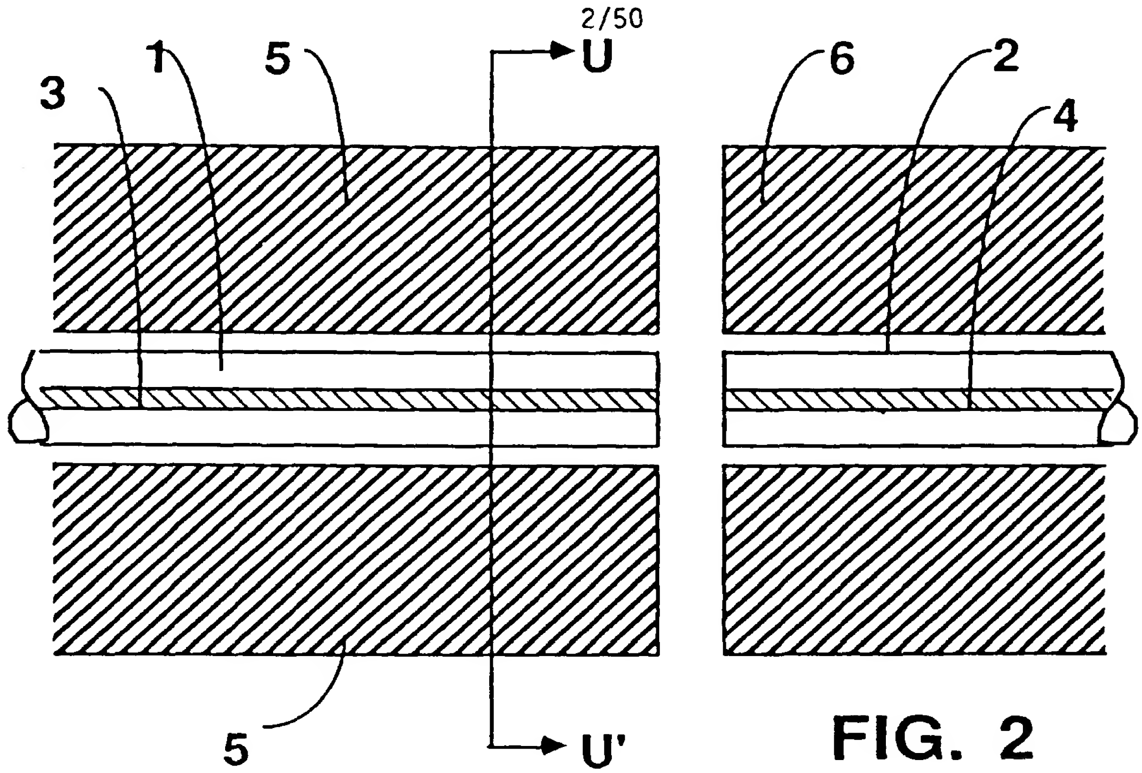

FIG. 2
(Prior Art)

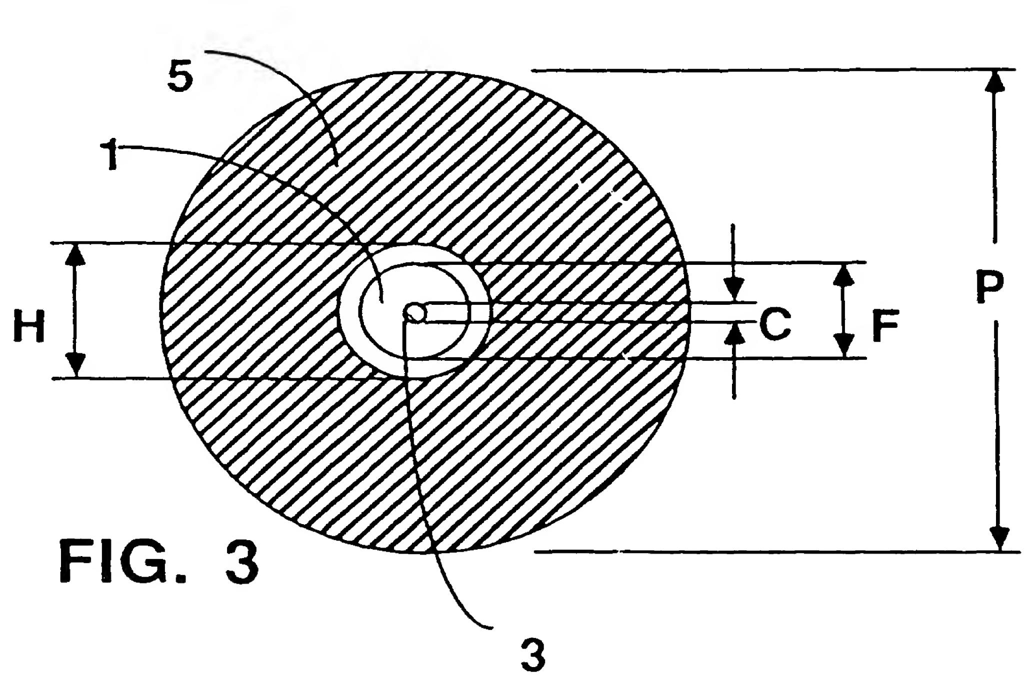

FIG. 3

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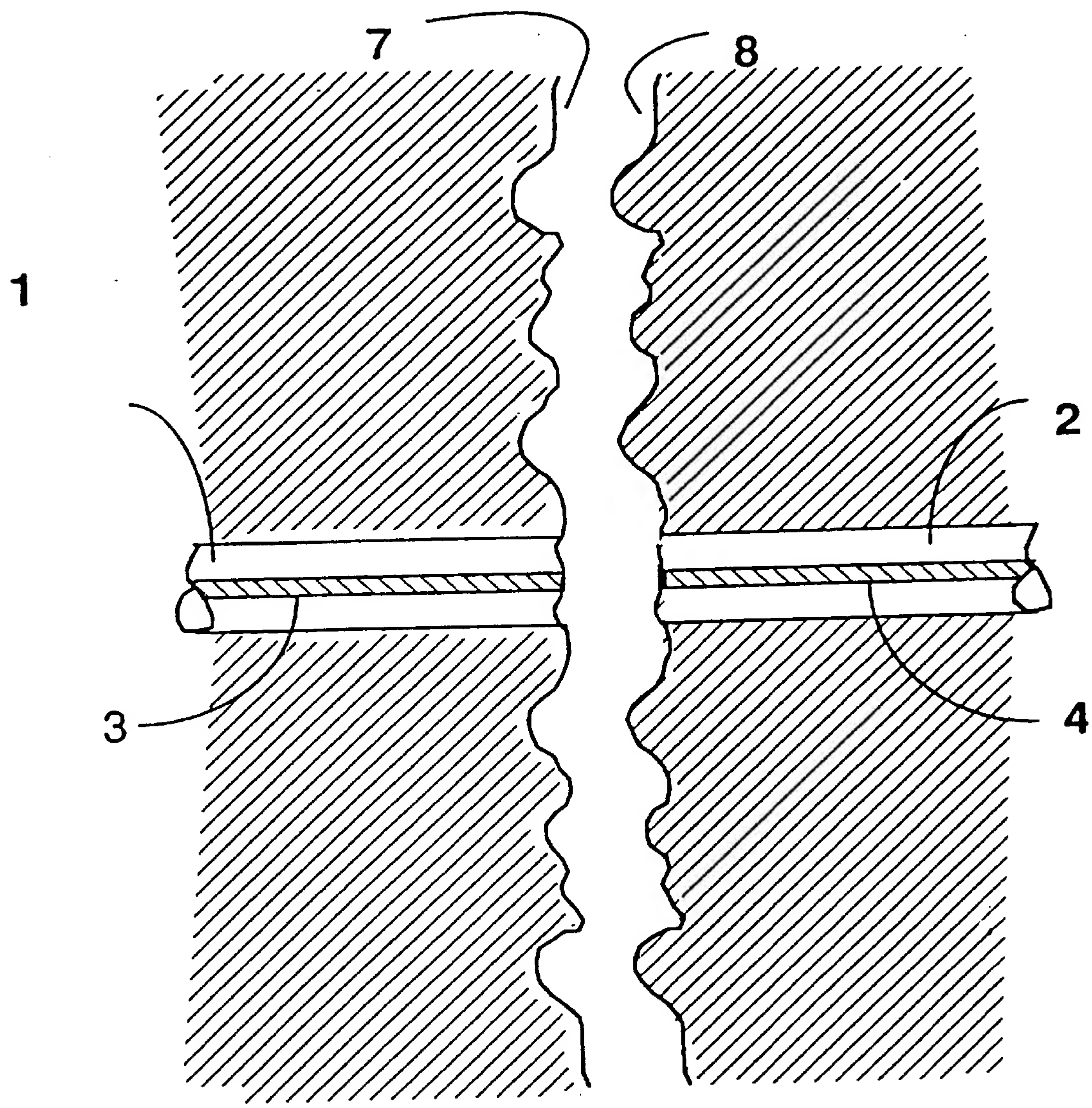


FIG. 4

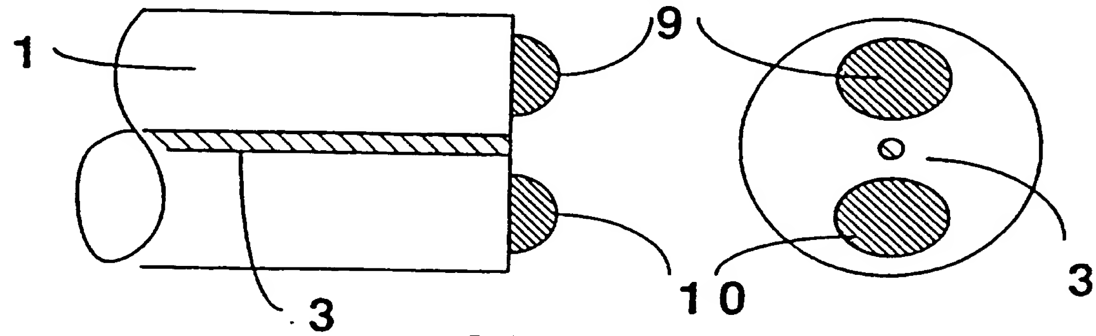


FIG. 5

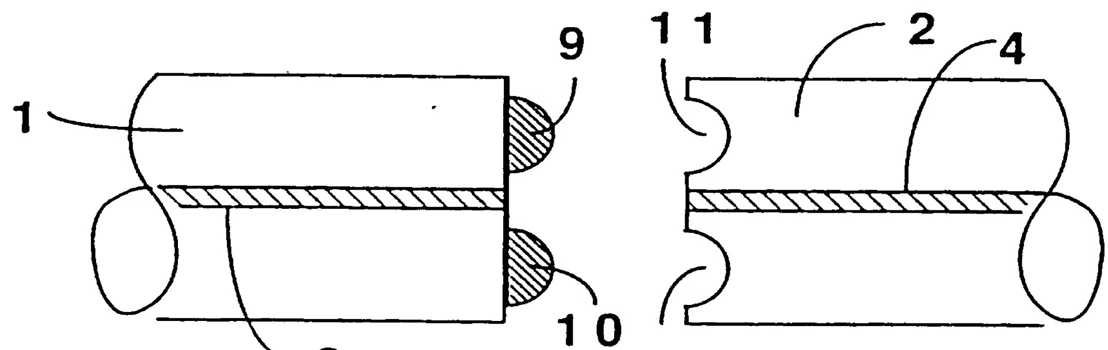


FIG.6

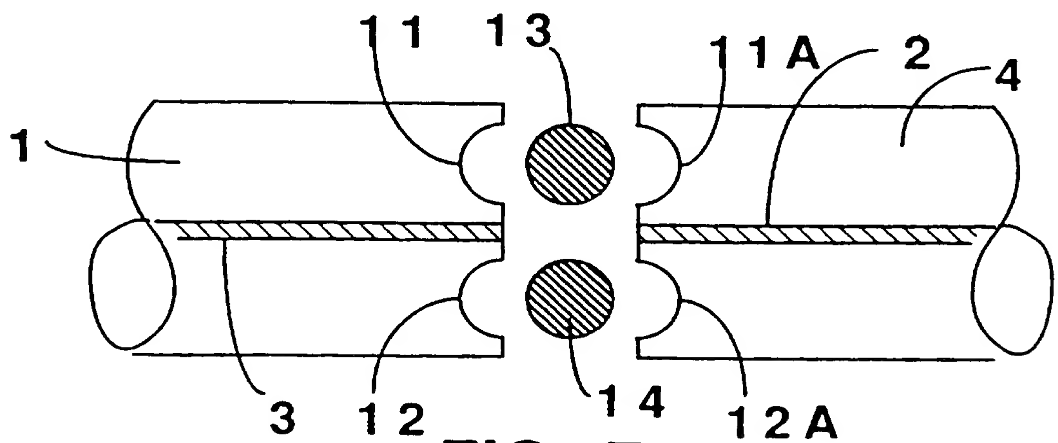


FIG. 7

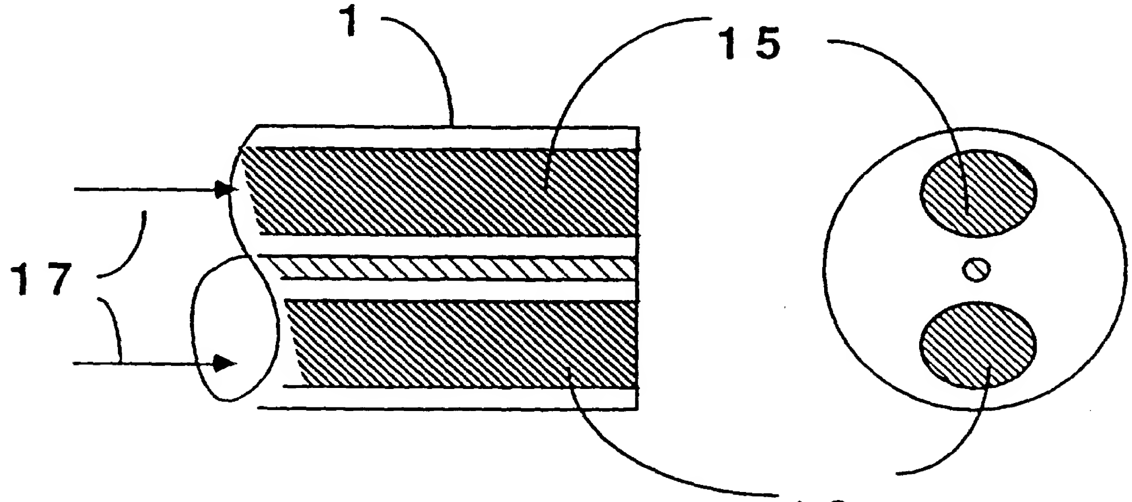
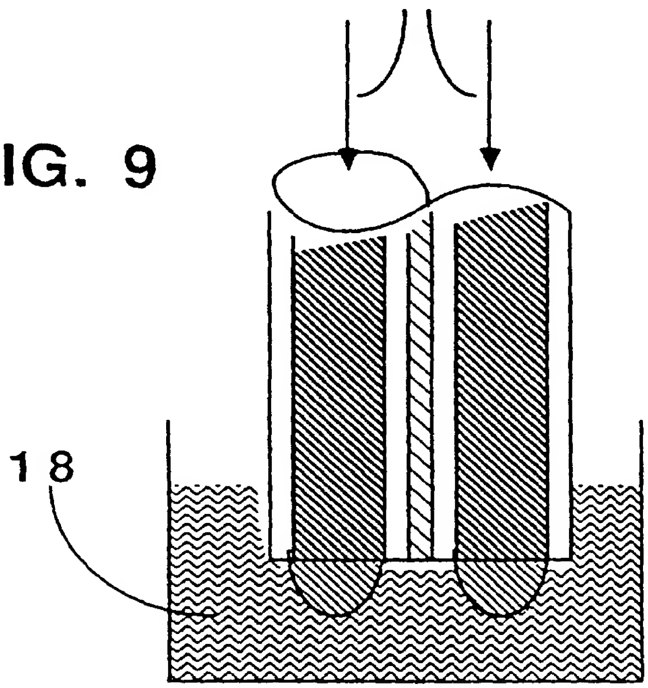


FIG. 8

FIG. 9



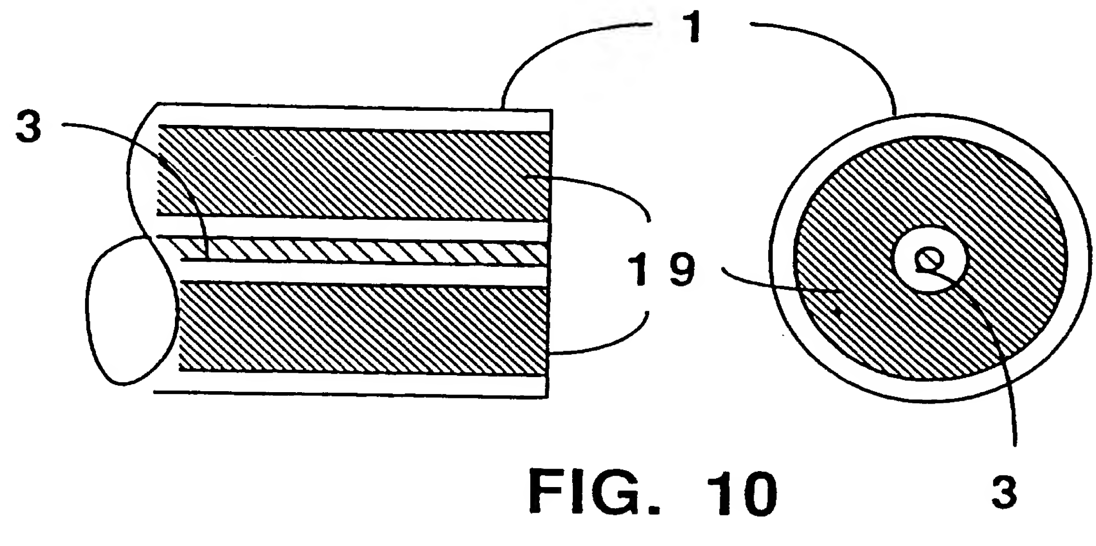


FIG. 10

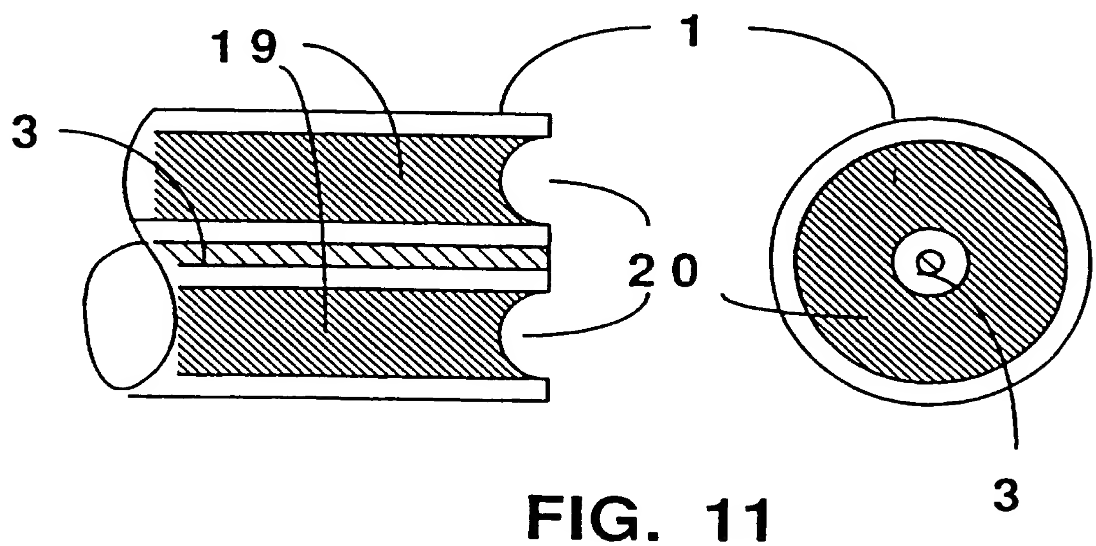


FIG. 11

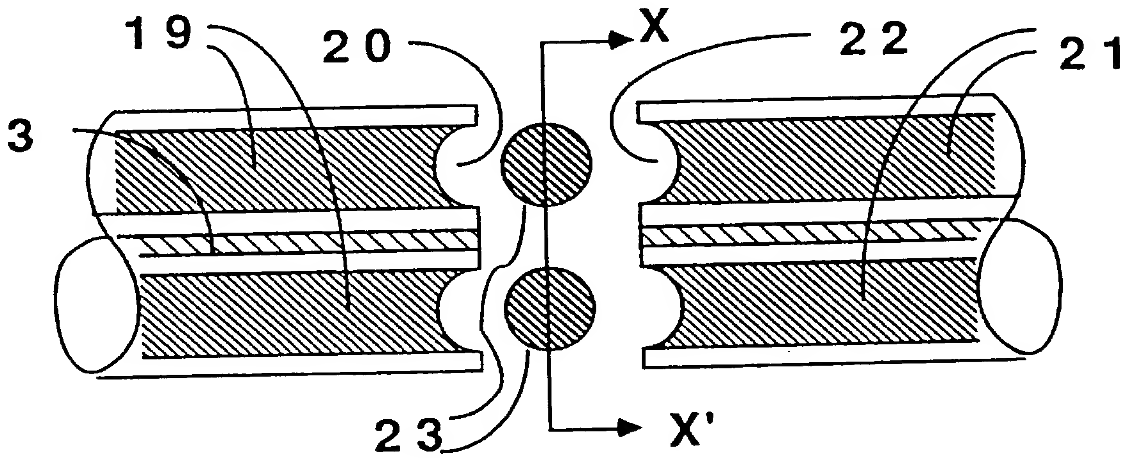


FIG. 12

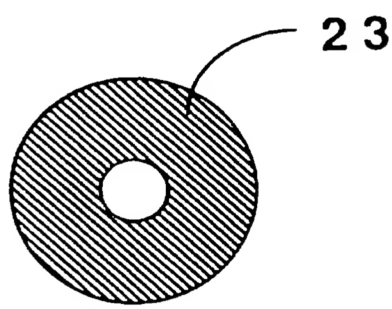


FIG. 13

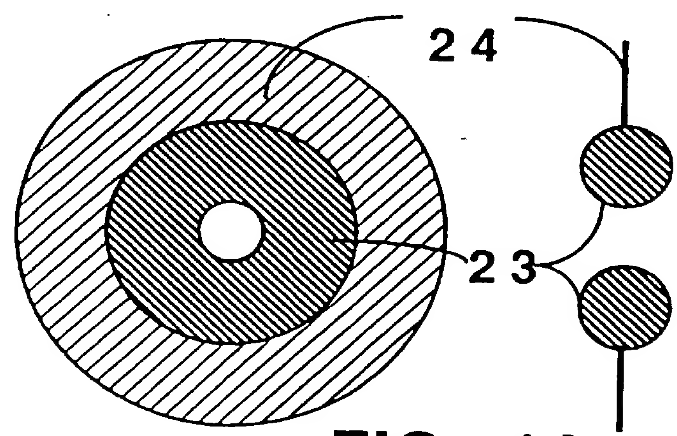


FIG. 14

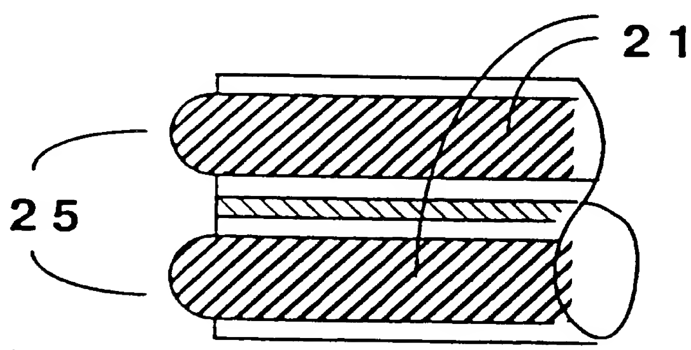


FIG. 15

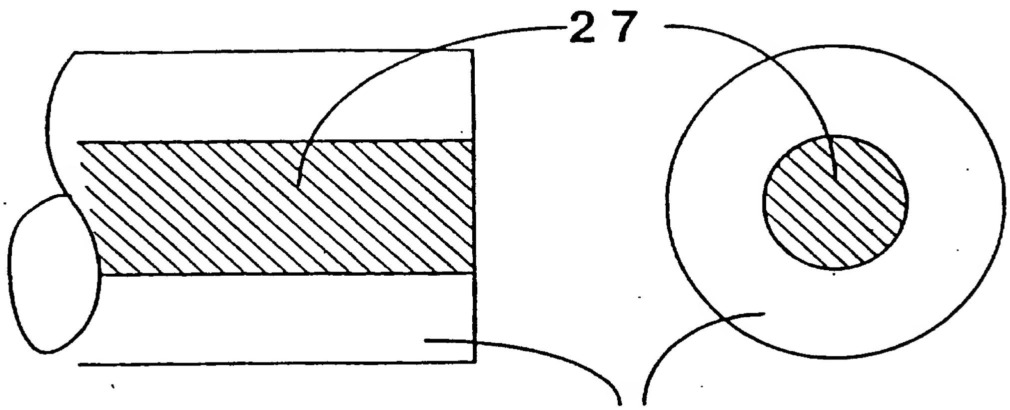


FIG. 16

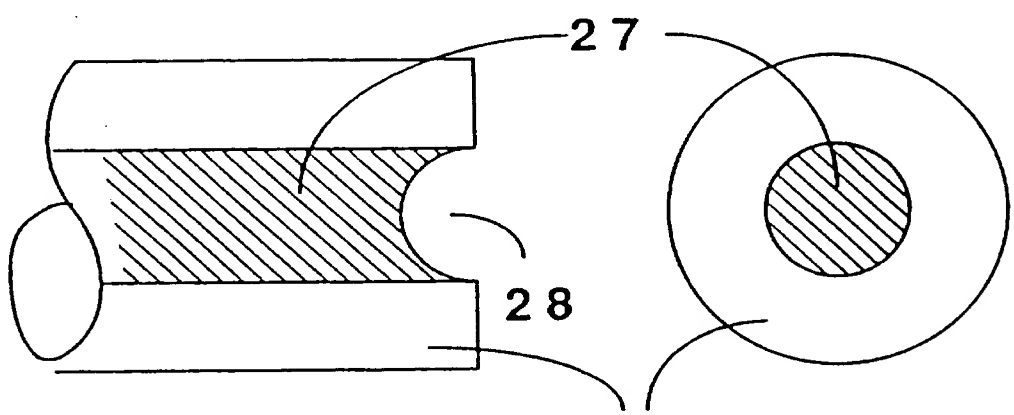


FIG. 17

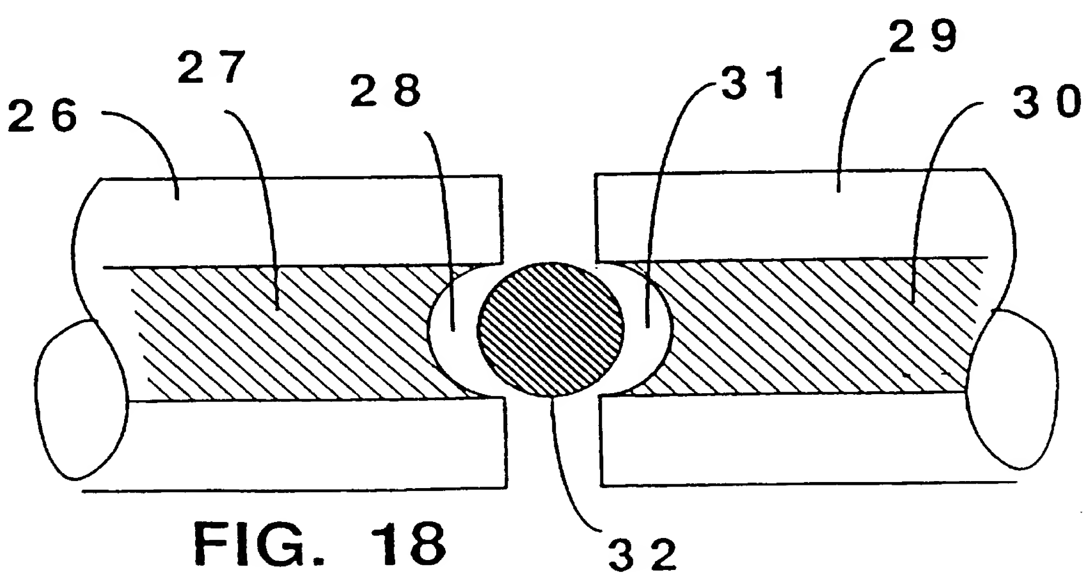


FIG. 18

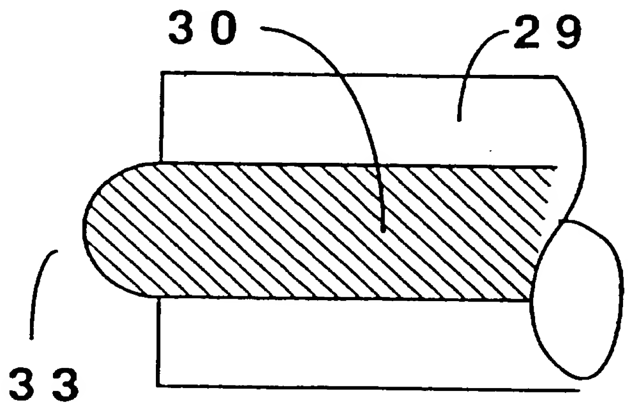


FIG. 19

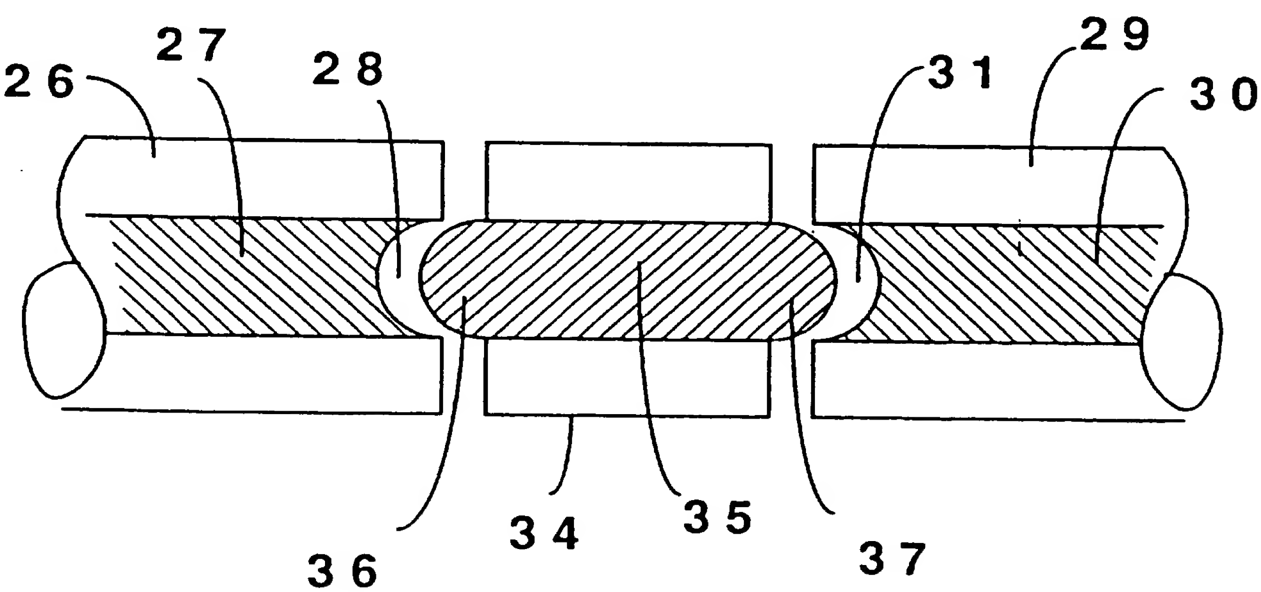


FIG. 20

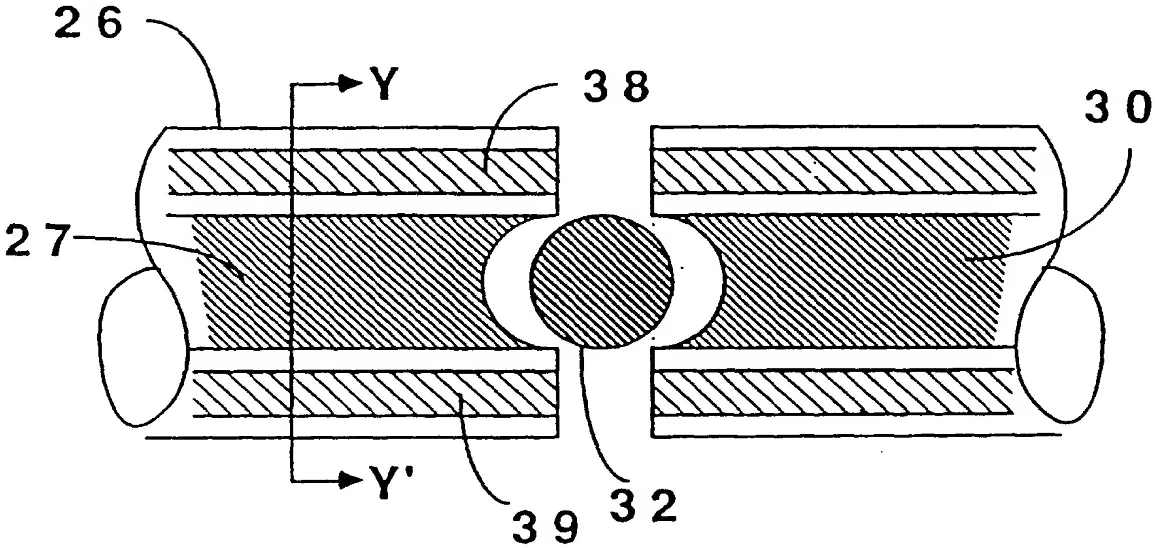


FIG. 21

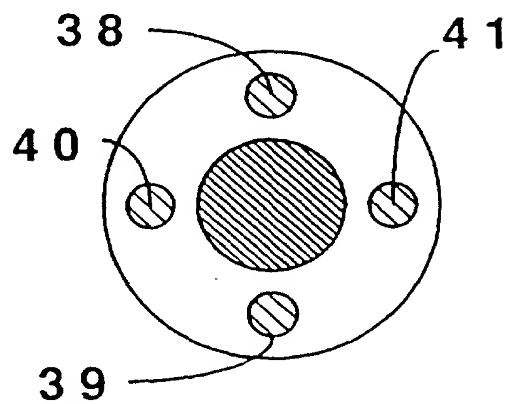


FIG. 22

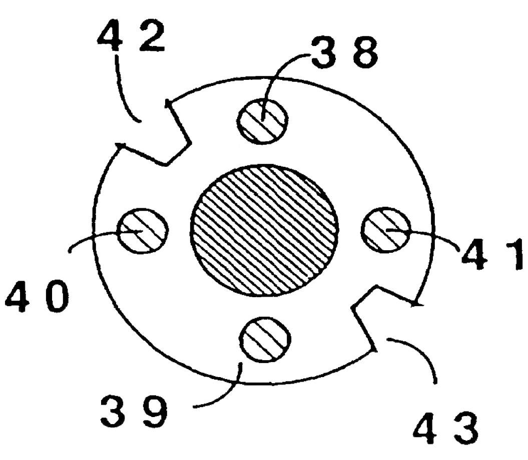


FIG. 23

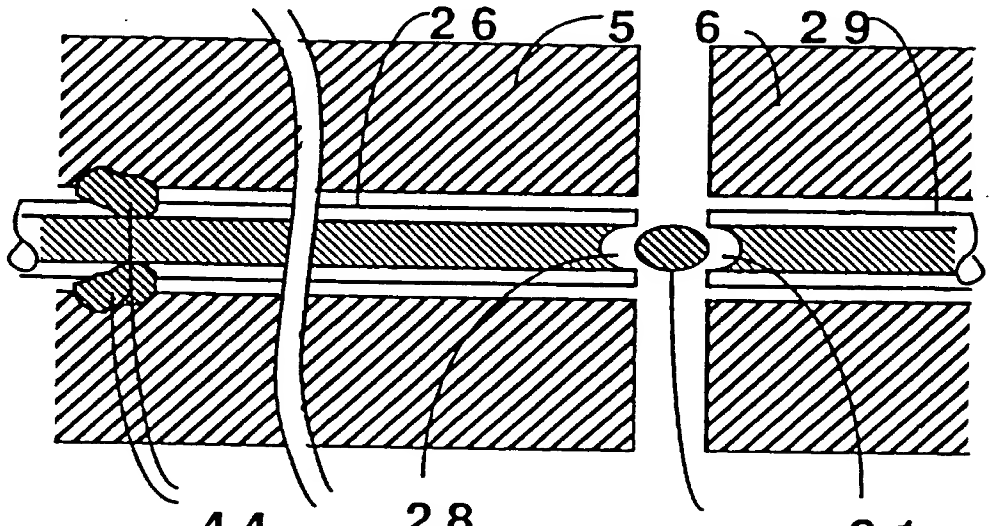


FIG. 24

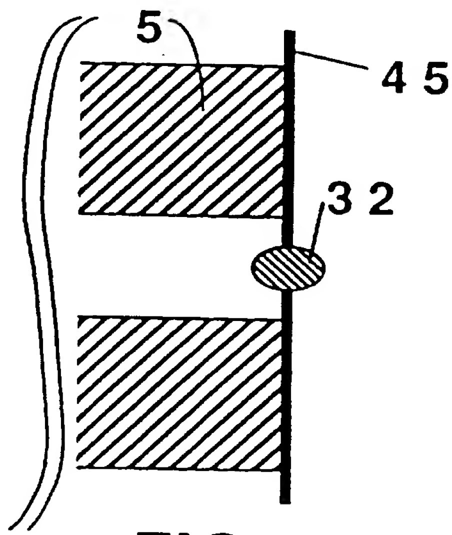
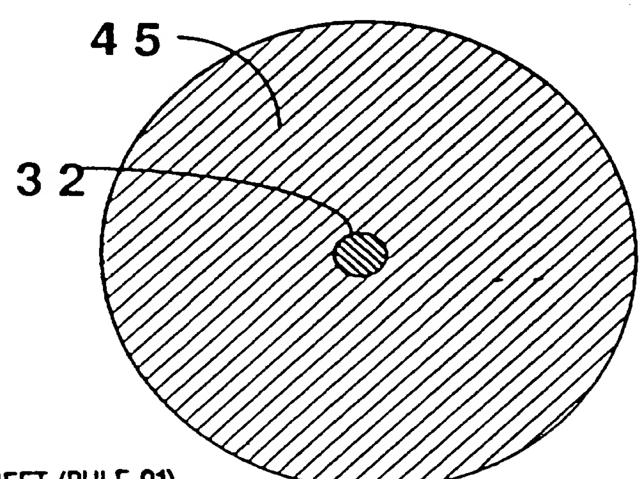


FIG. 25

FIG. 26



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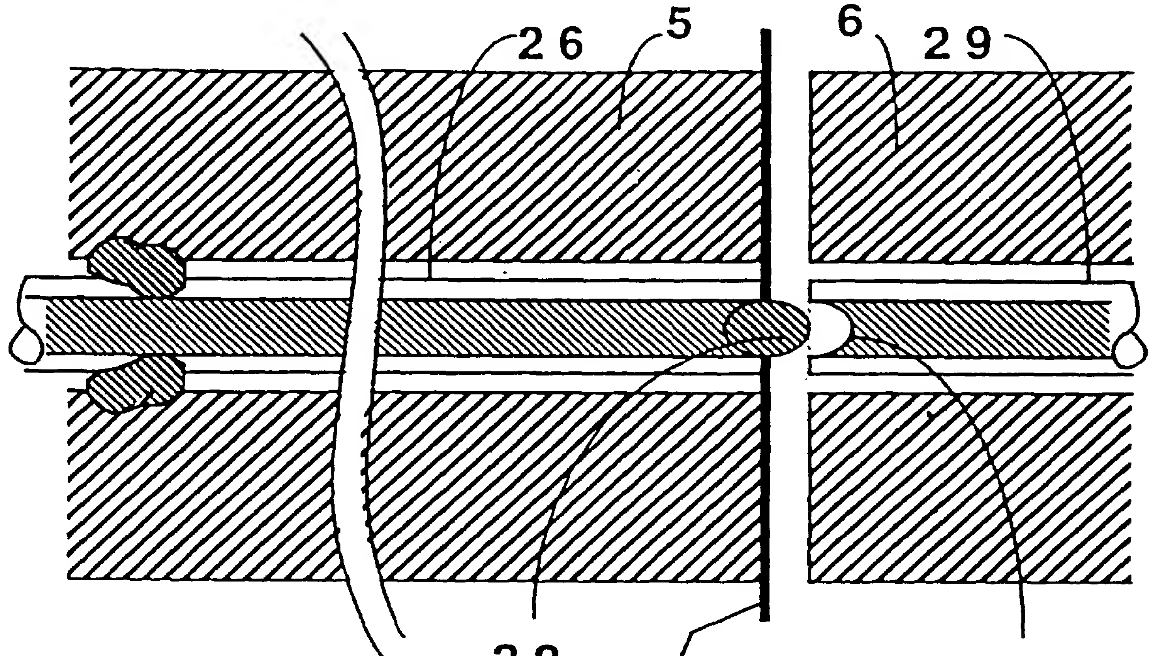

FIG. 27

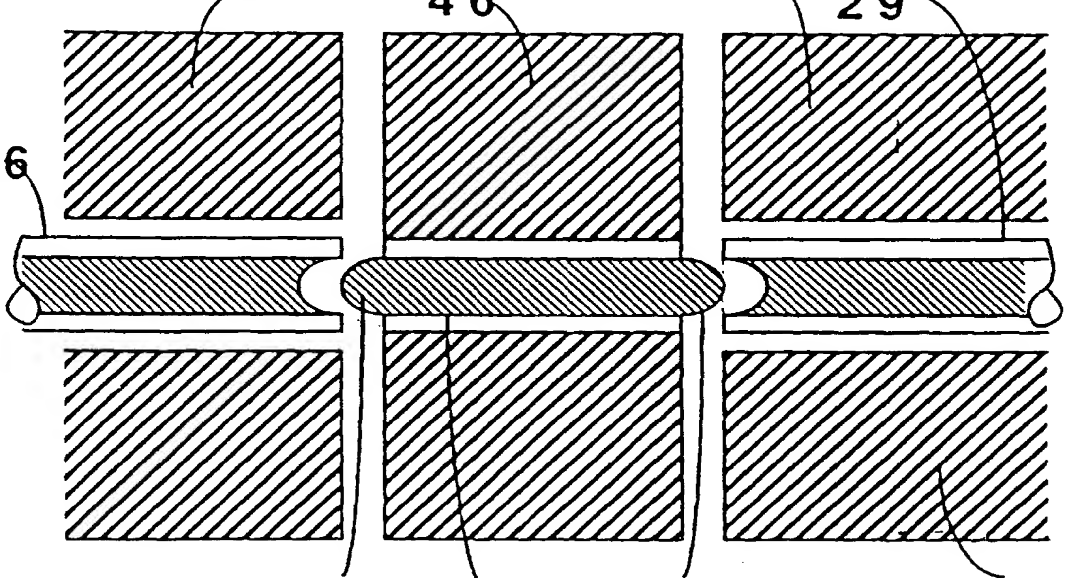

FIG. 28

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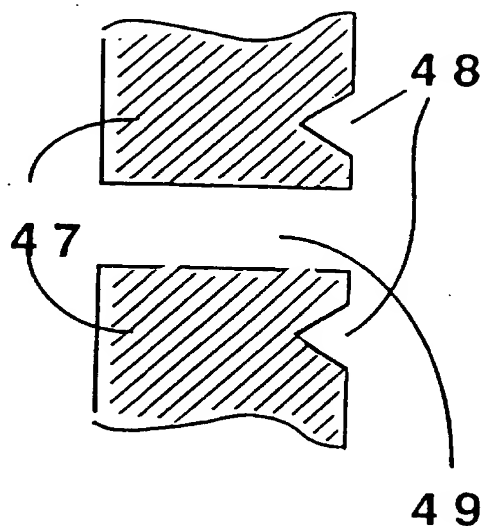

FIG. 29

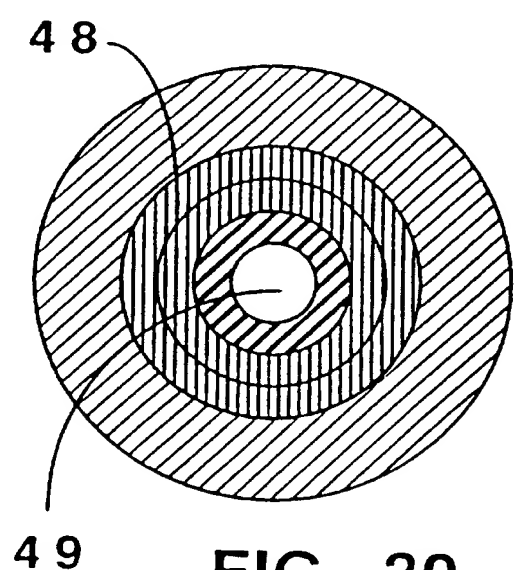

FIG. 30

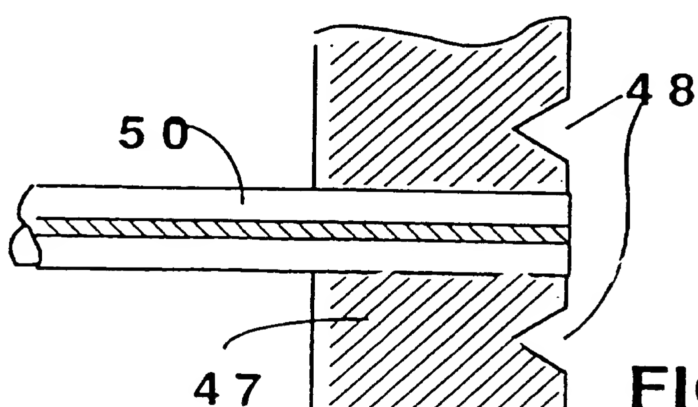

FIG. 31

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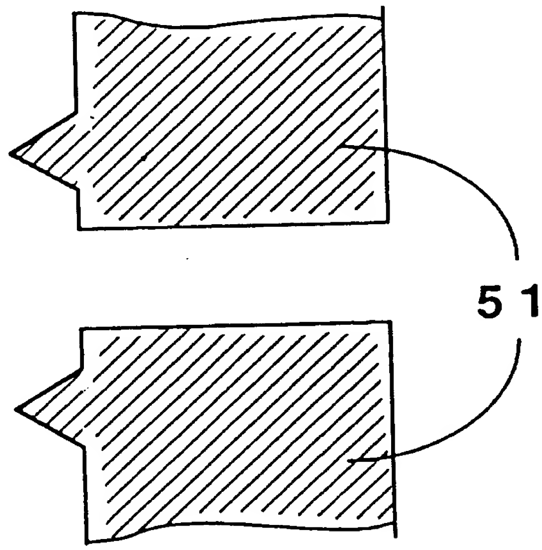


FIG. 32

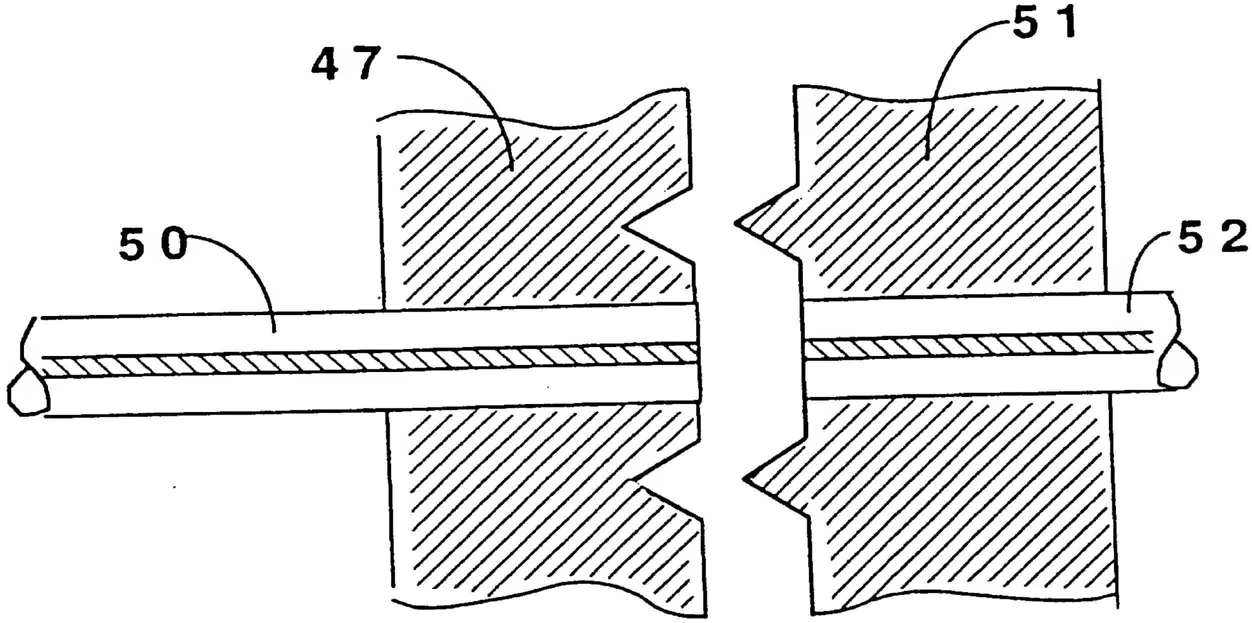


FIG. 33

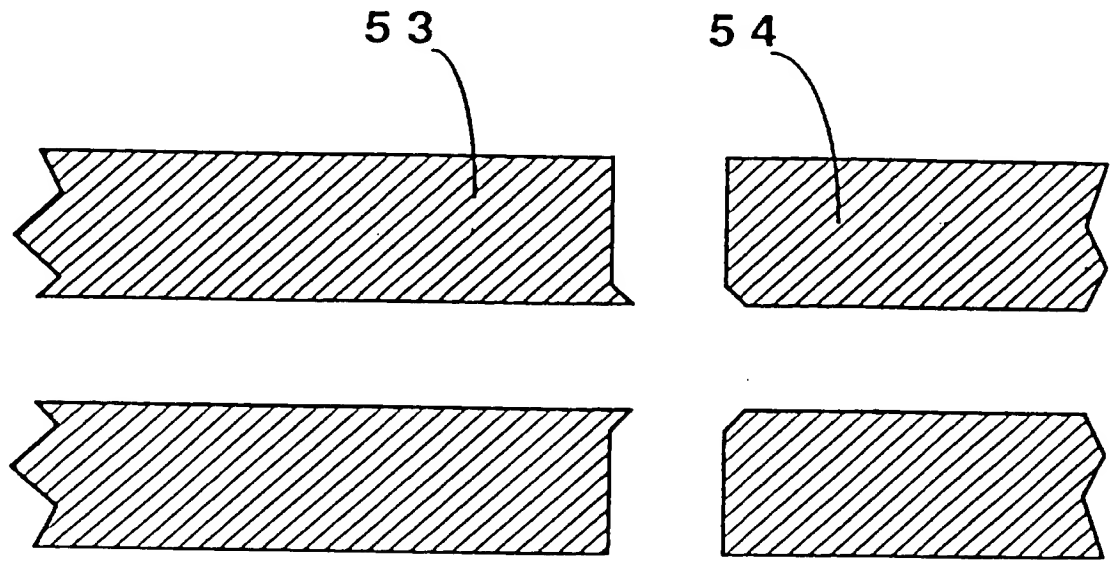


FIG. 34

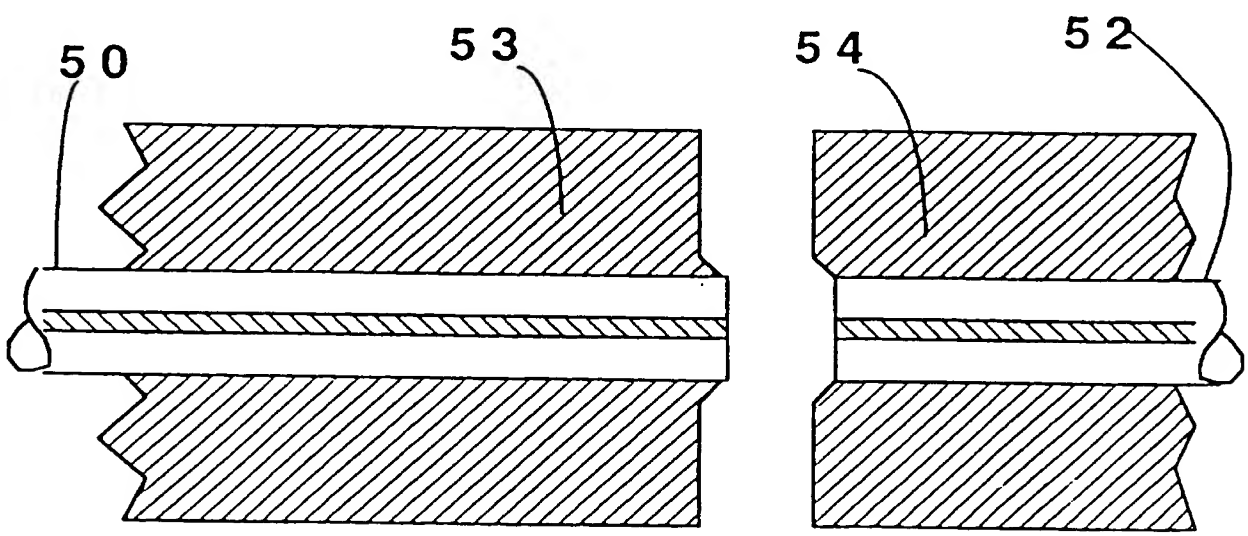


FIG. 35

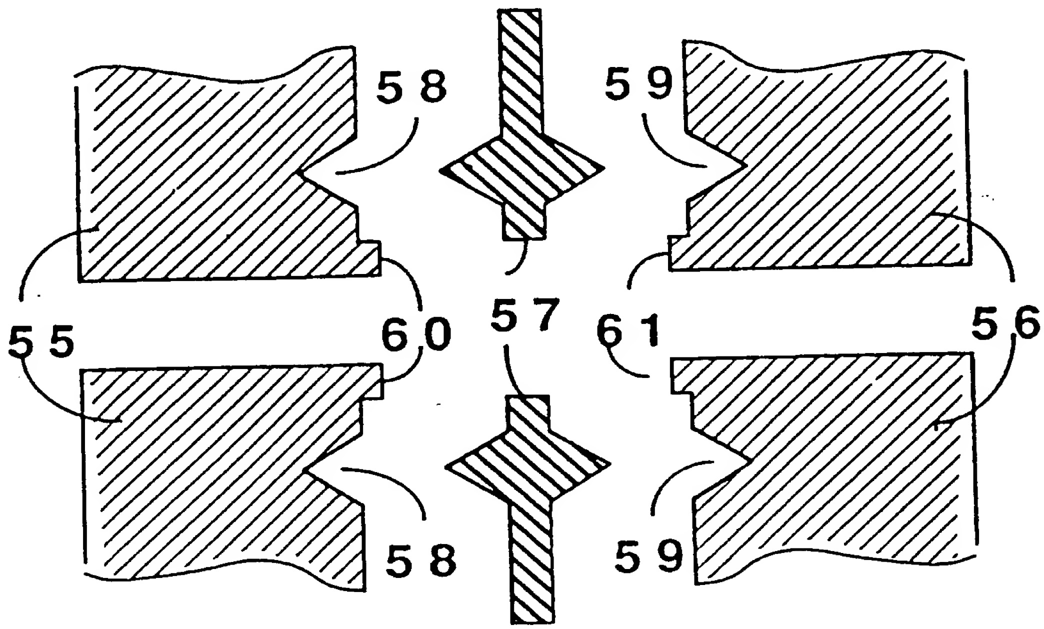
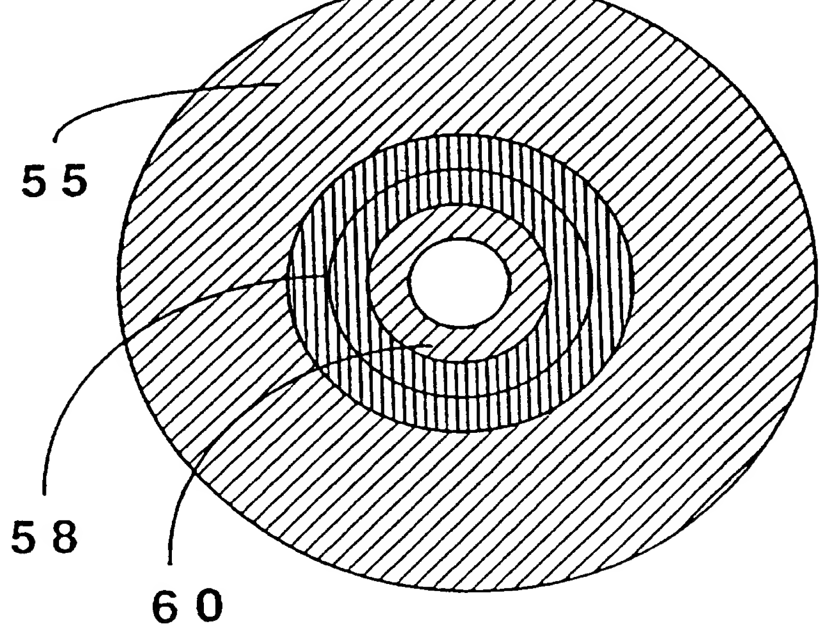


FIG. 36

FIG. 37



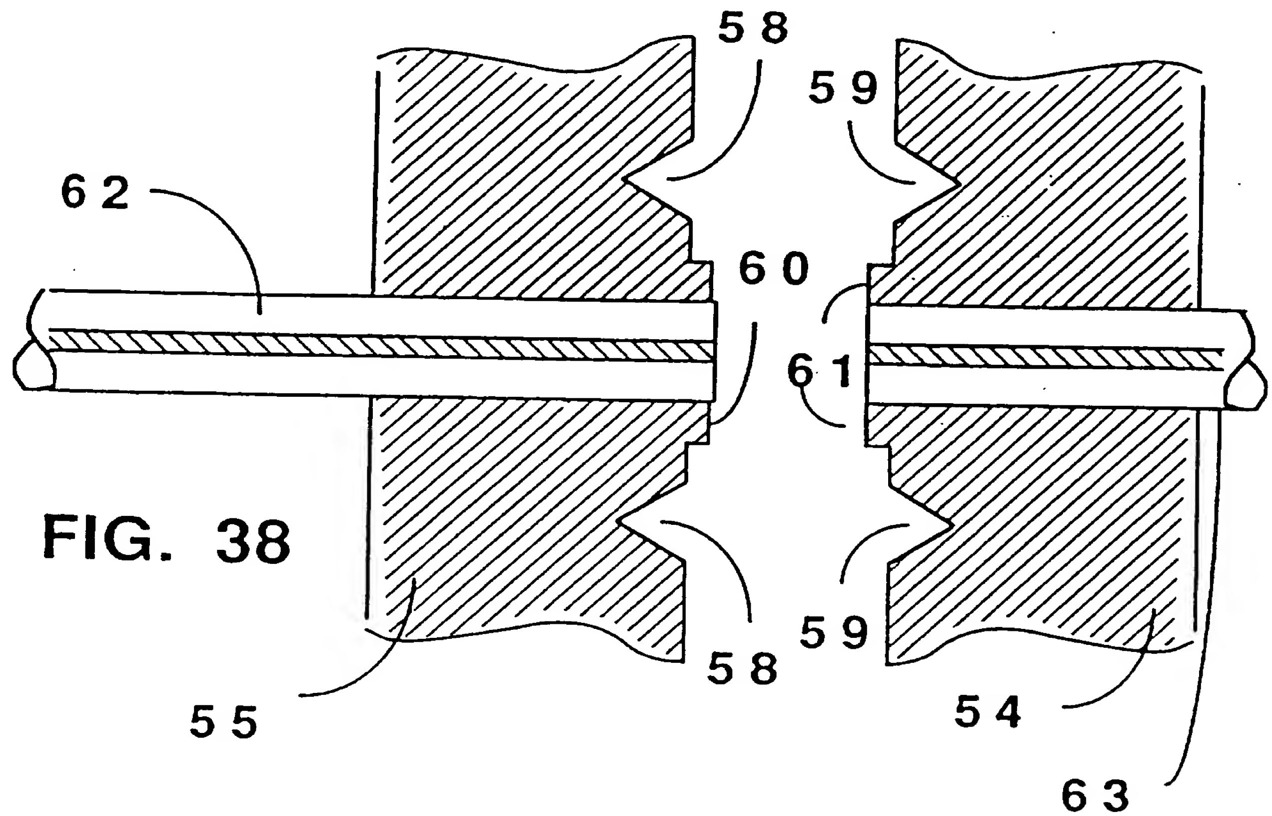


FIG. 38

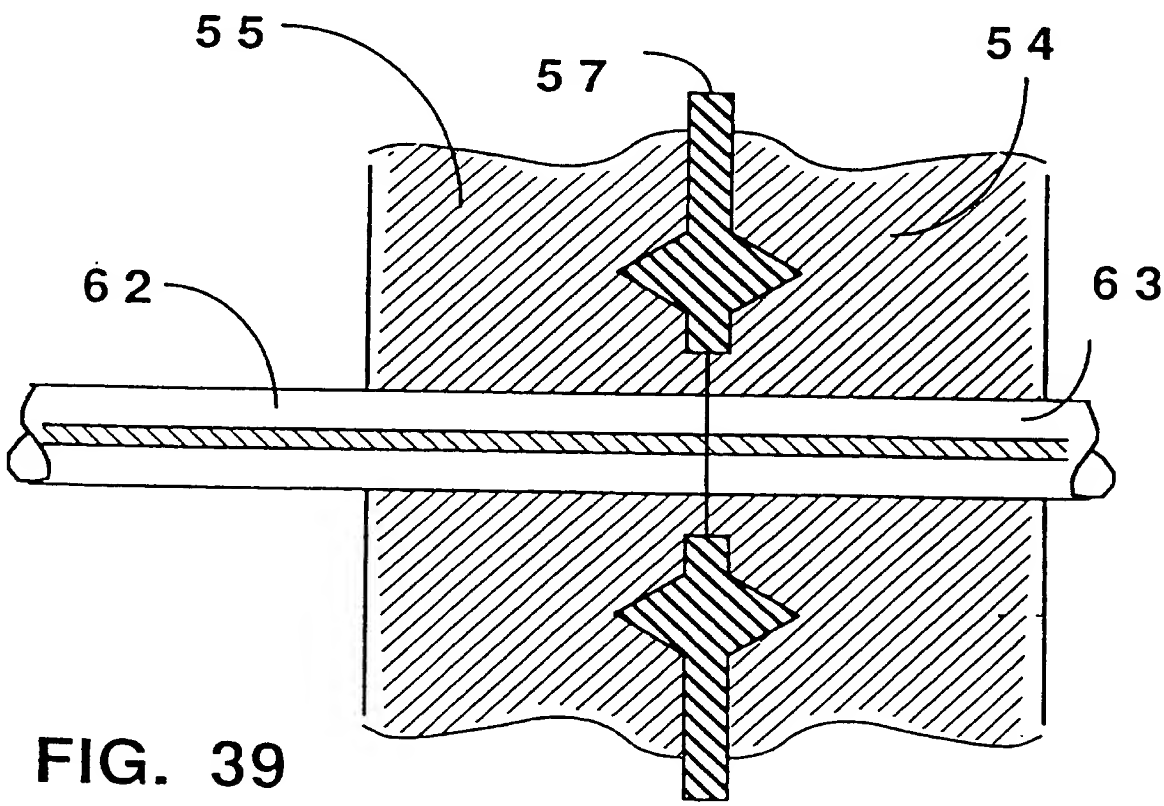


FIG. 39

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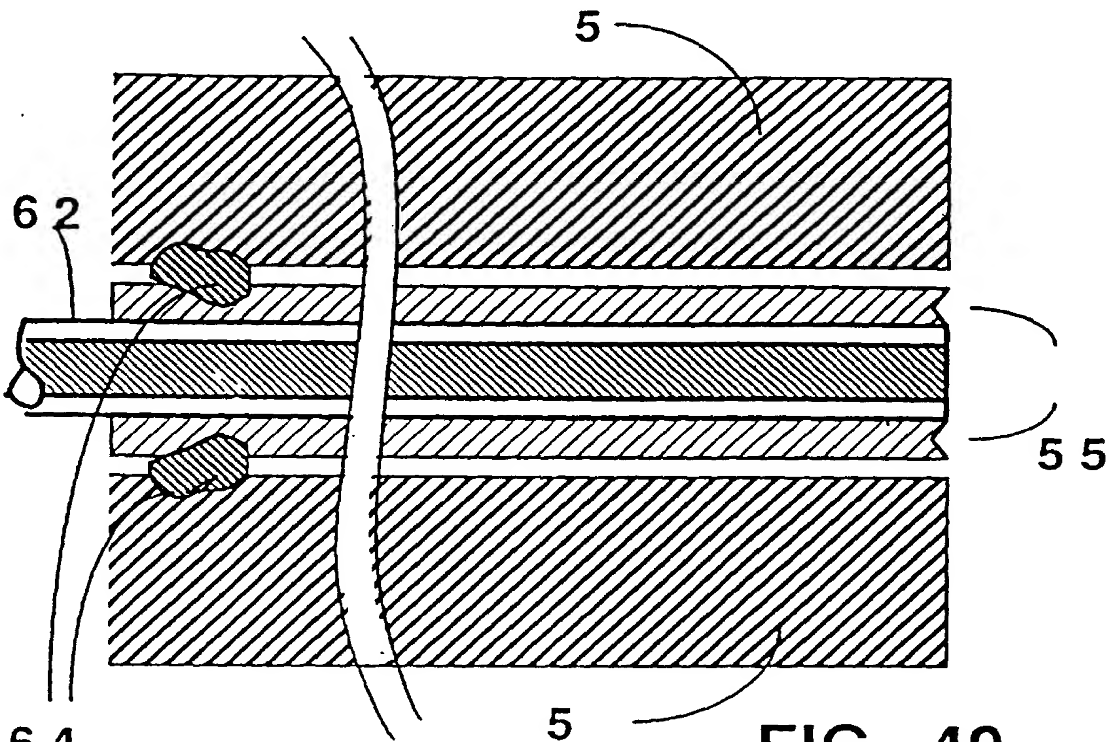

FIG. 40

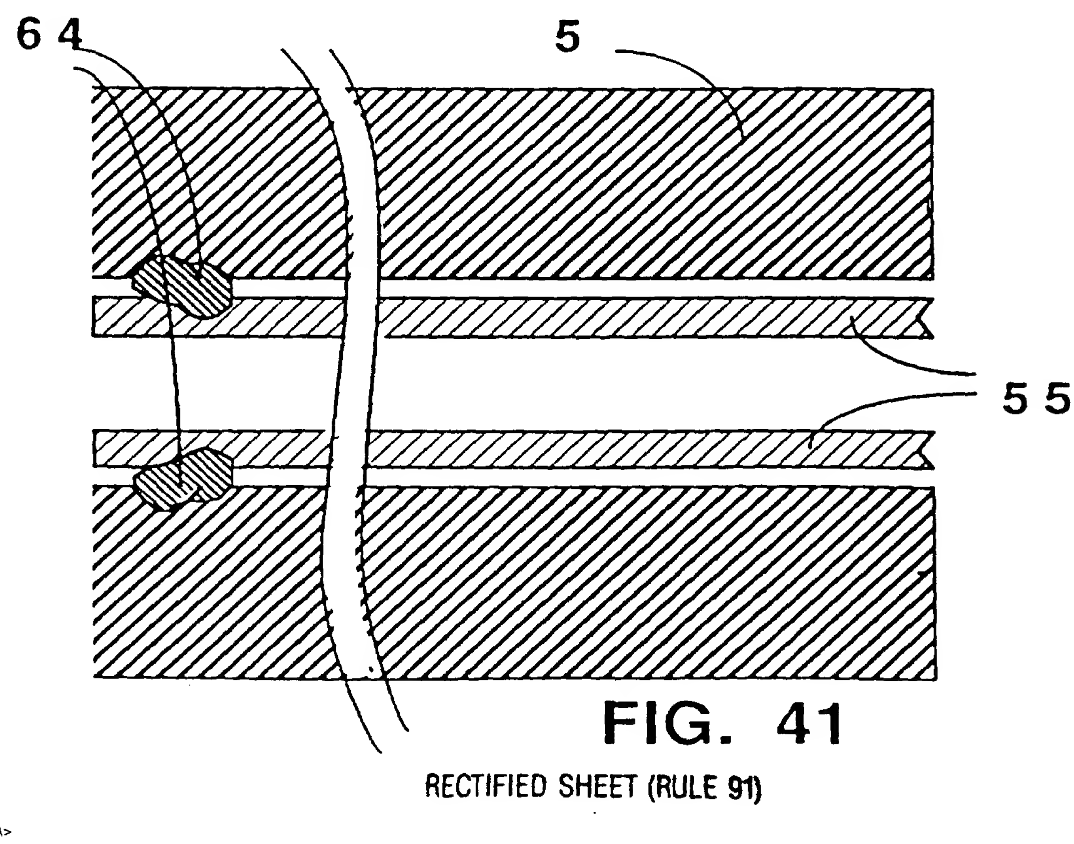

FIG. 41

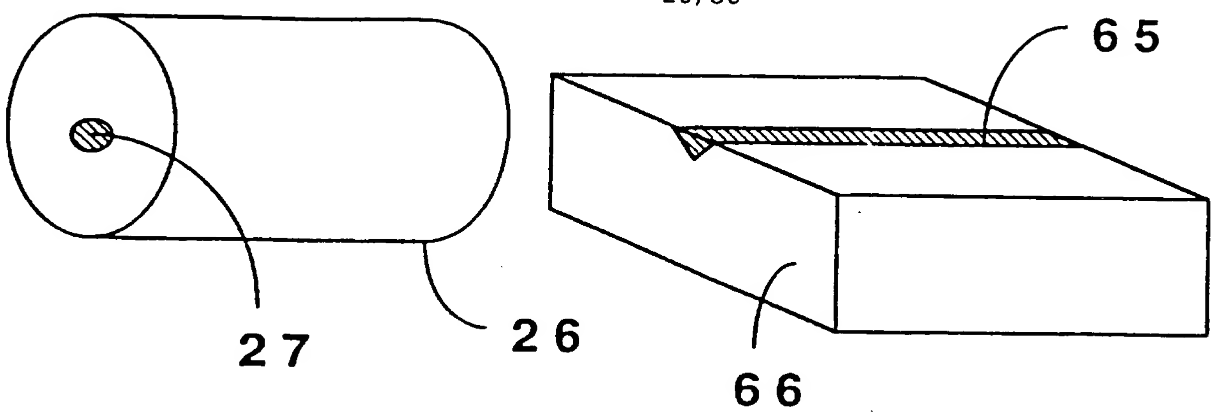

FIG. 42

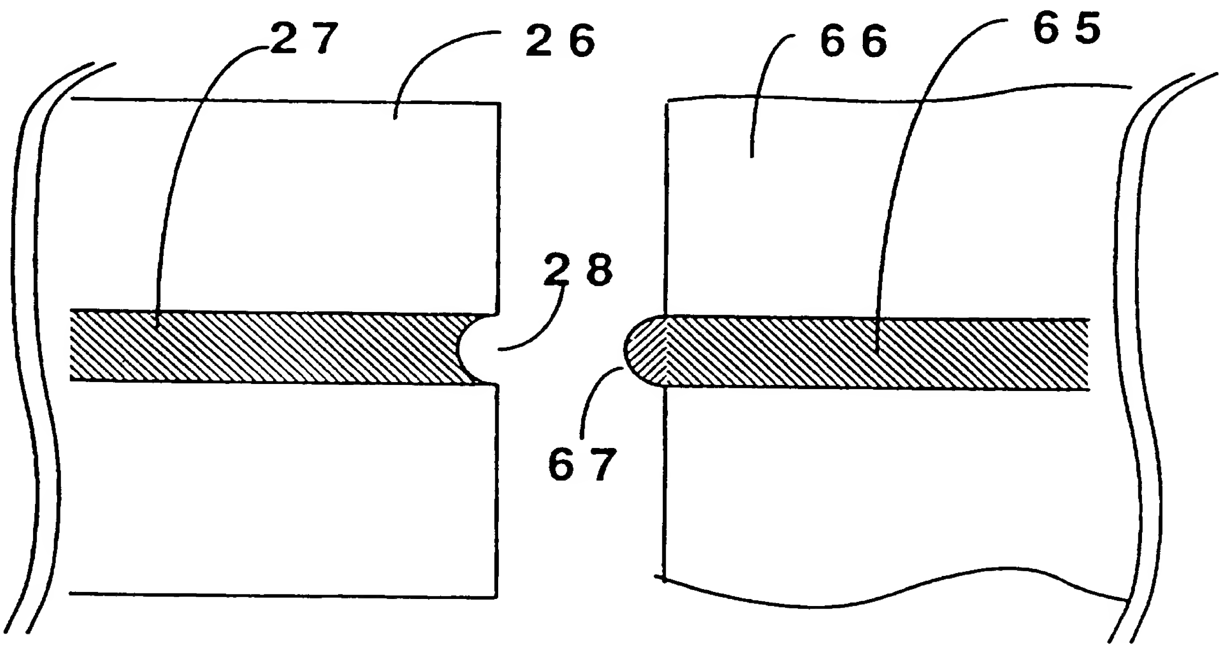

FIG. 43

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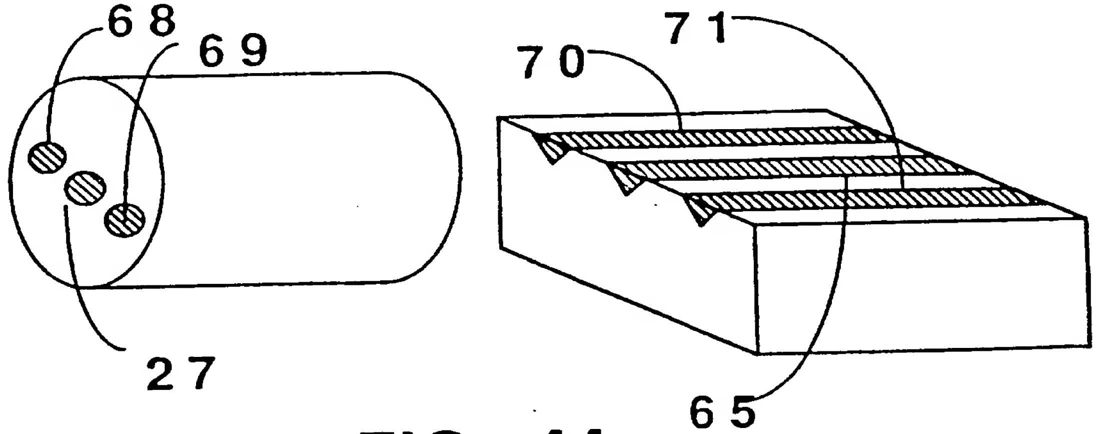

FIG. 44

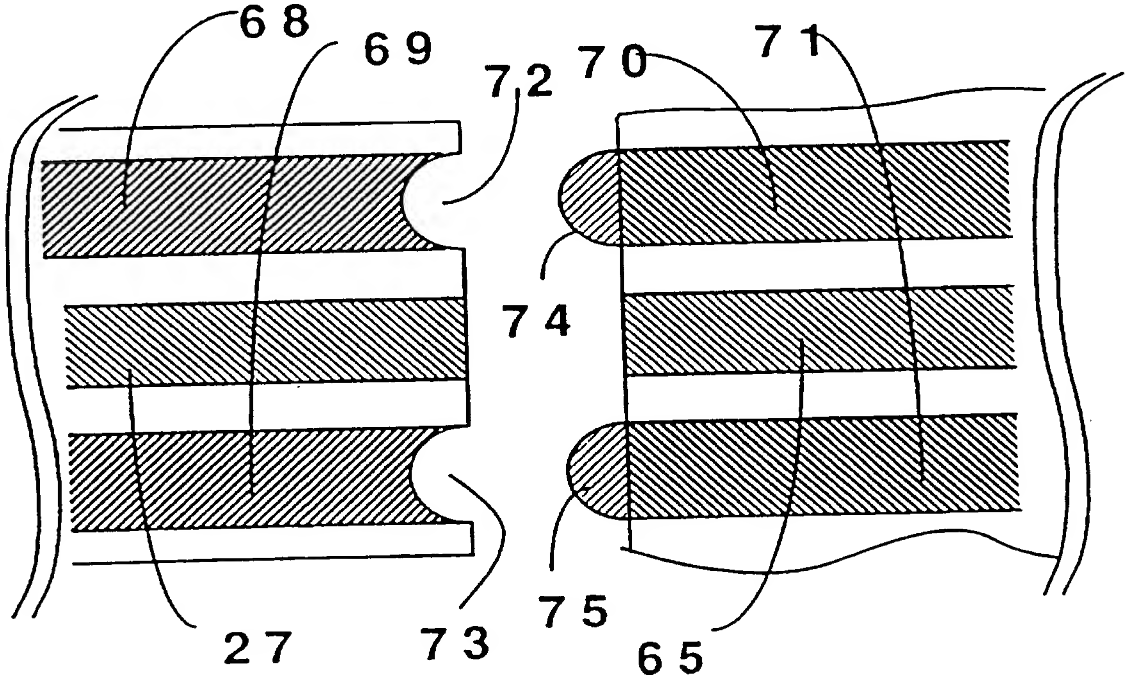

FIG. 45

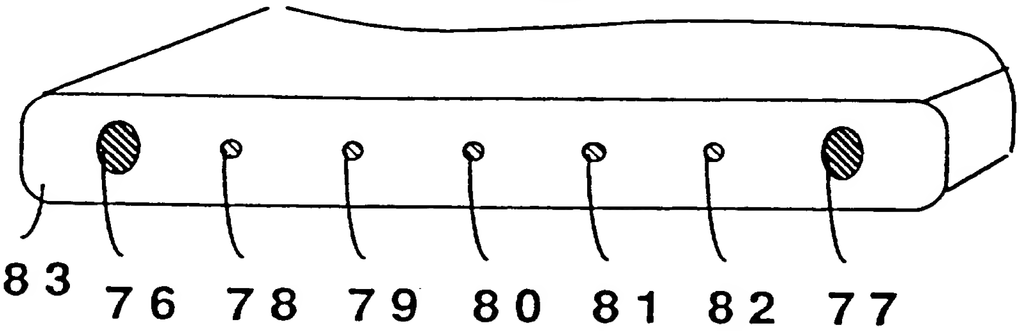

FIG. 46

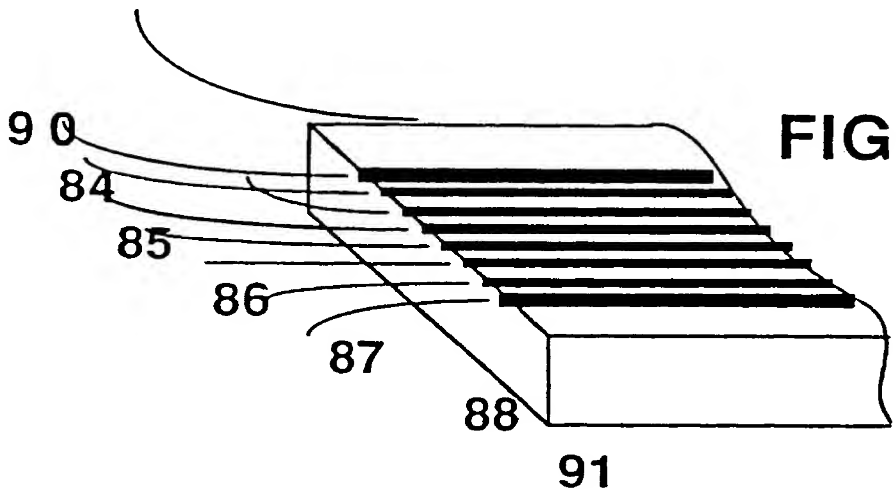

FIG. 47

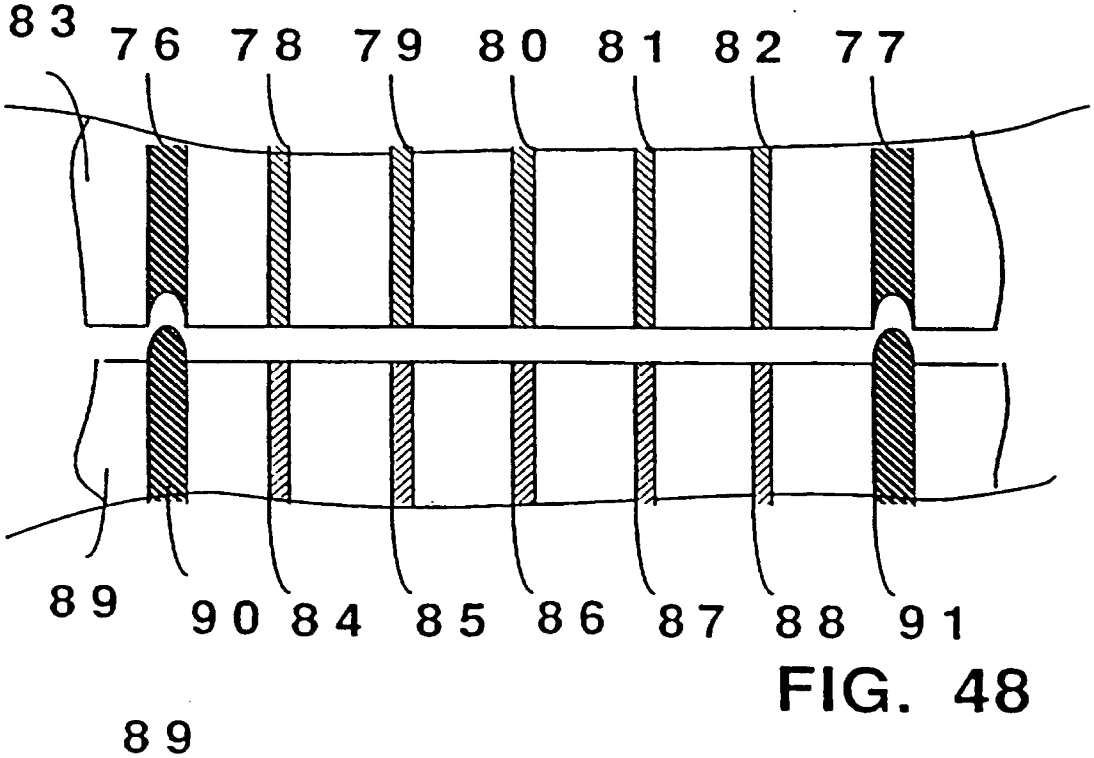

FIG. 48

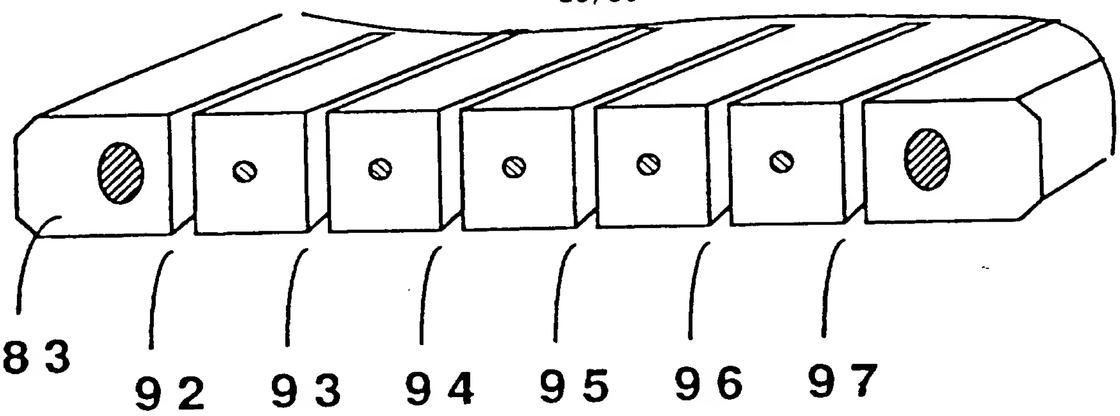

FIG. 49

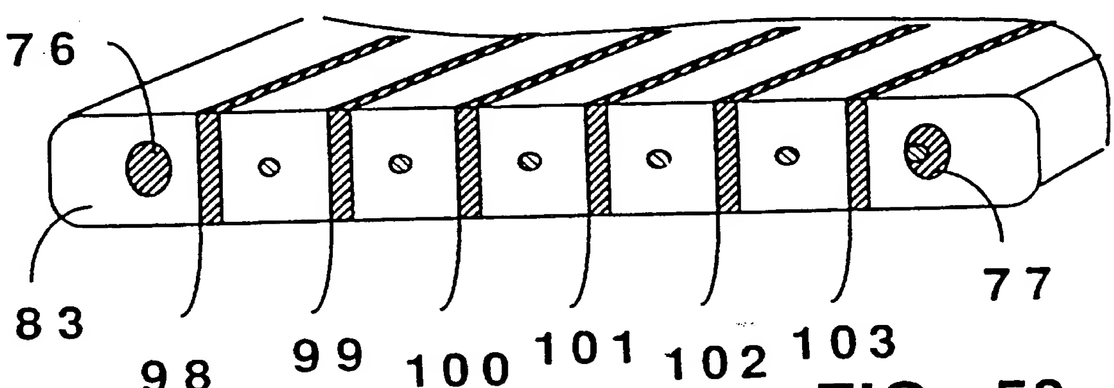

FIG. 50

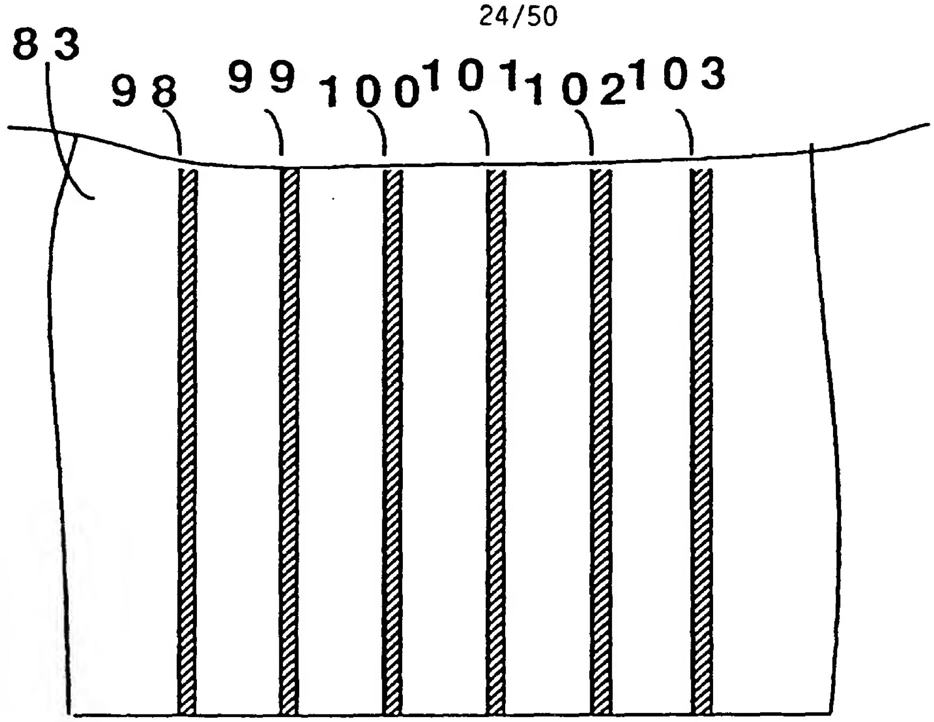

FIG. 51

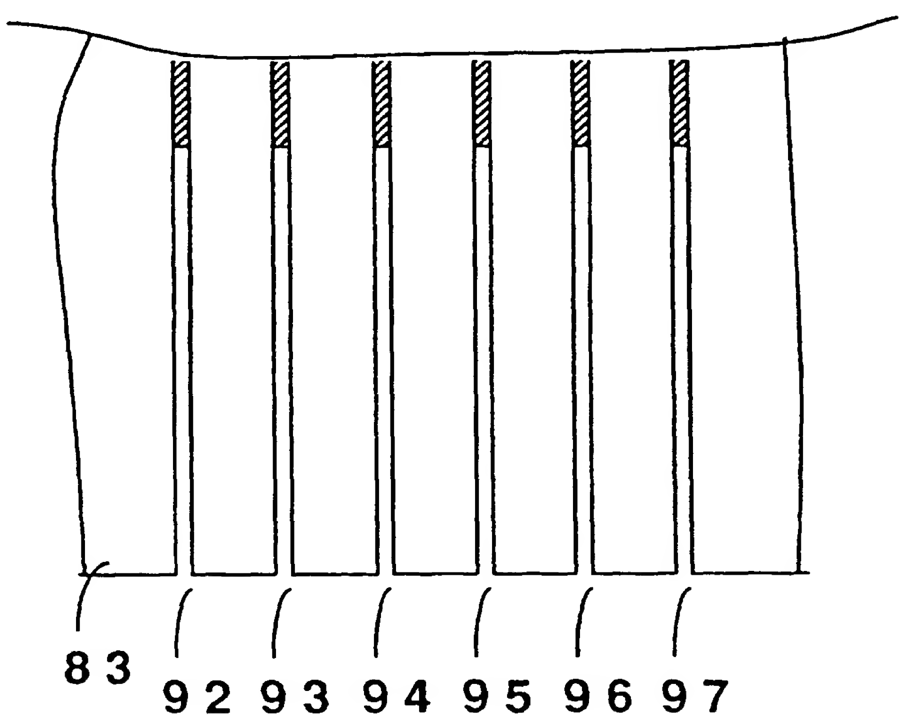

FIG. 52

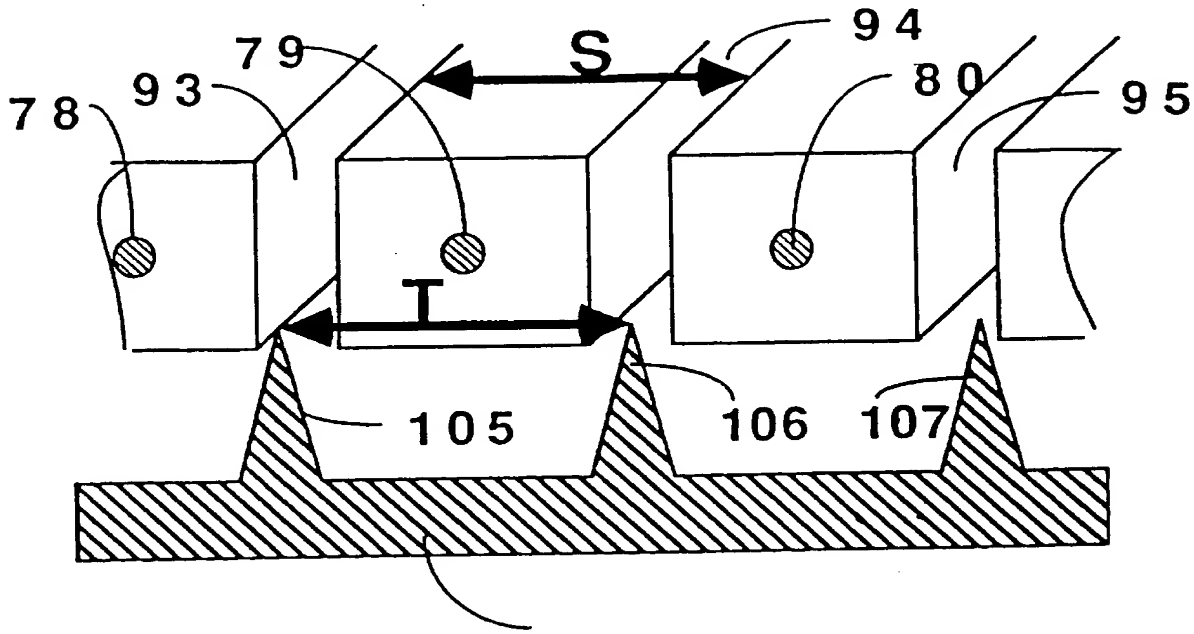

FIG. 53

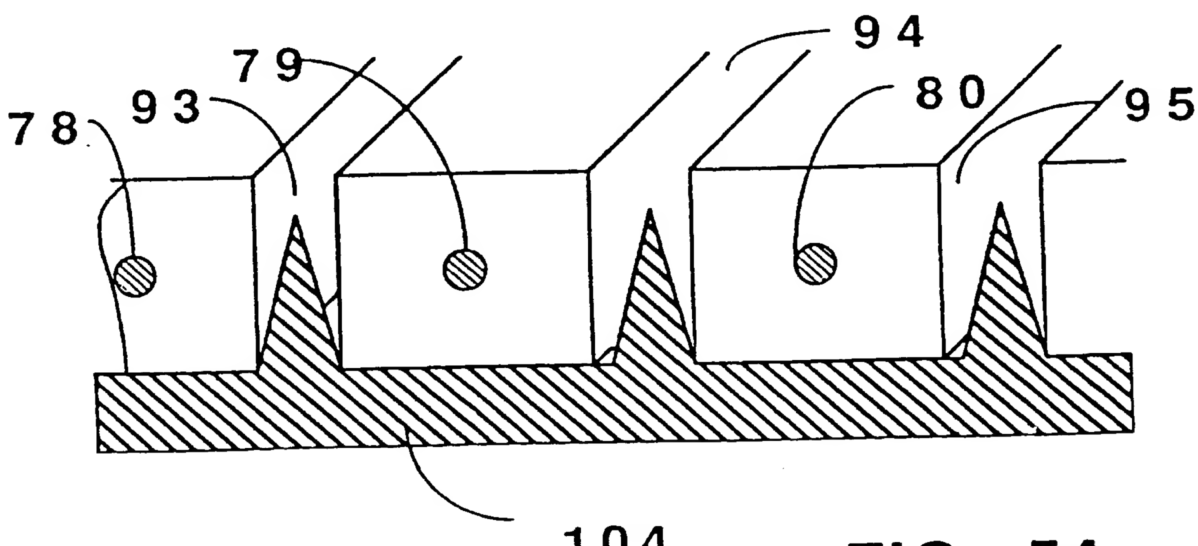

FIG. 54

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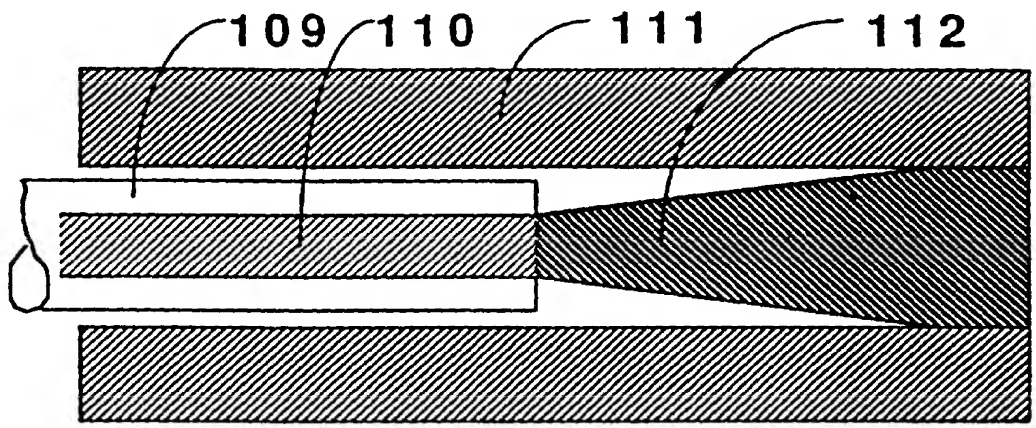

FIG. 55

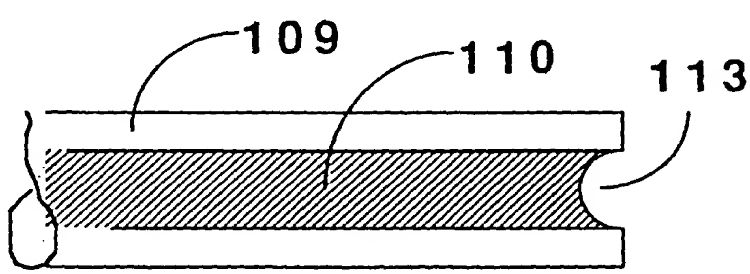

FIG. 56

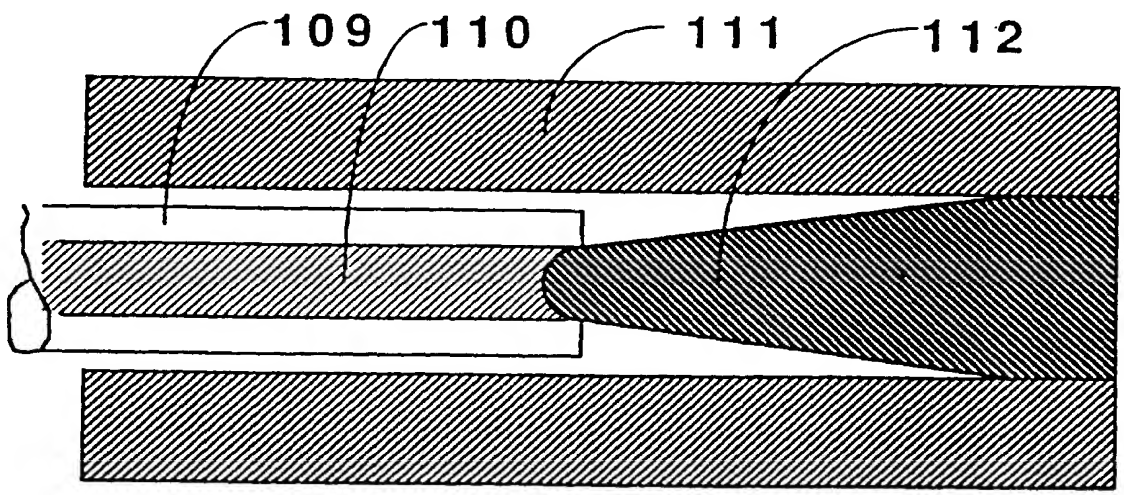

FIG. 57

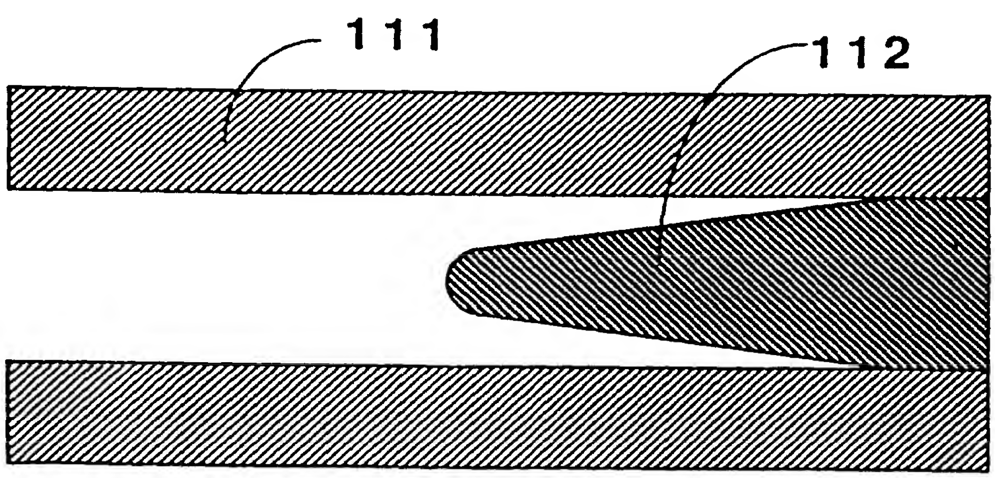

FIG. 58

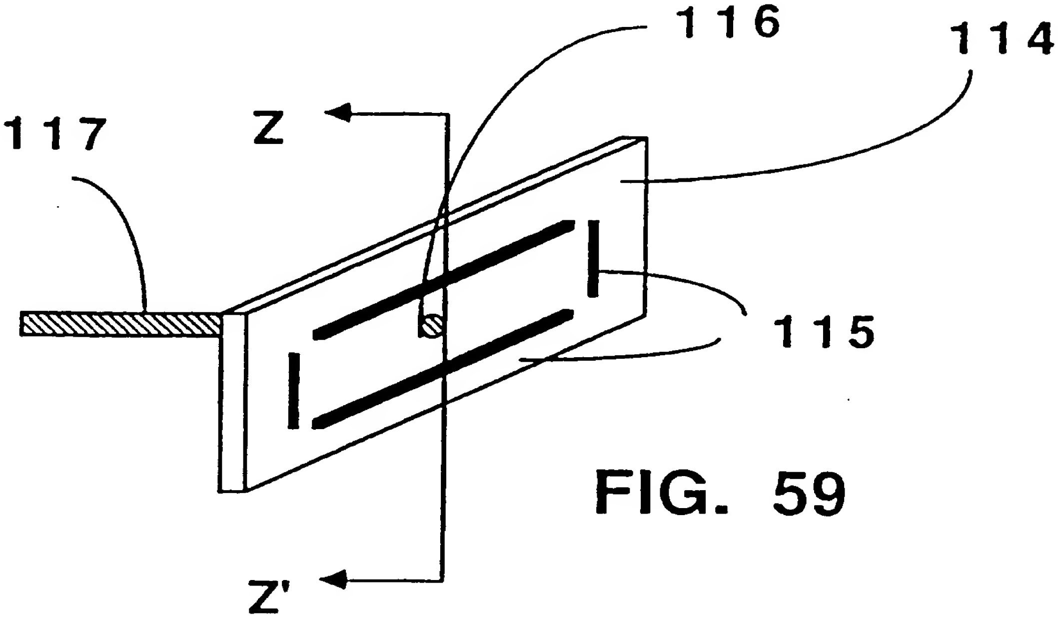

FIG. 59

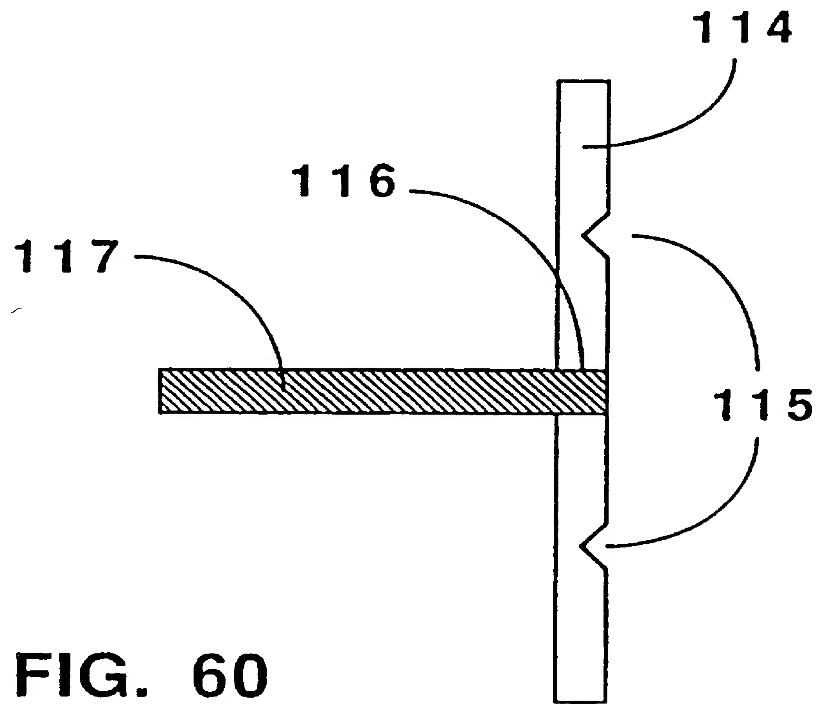

FIG. 60

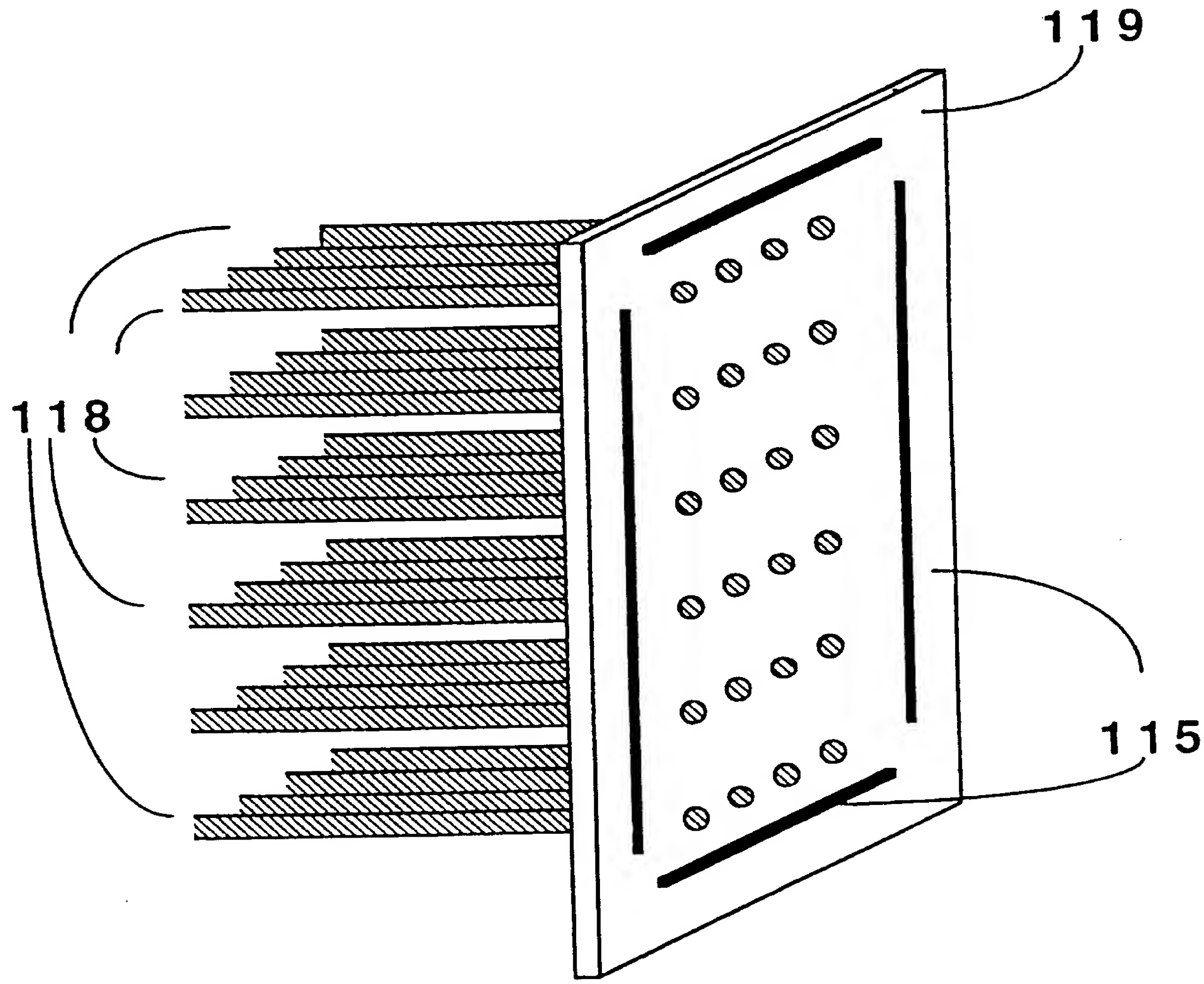

FIG. 61

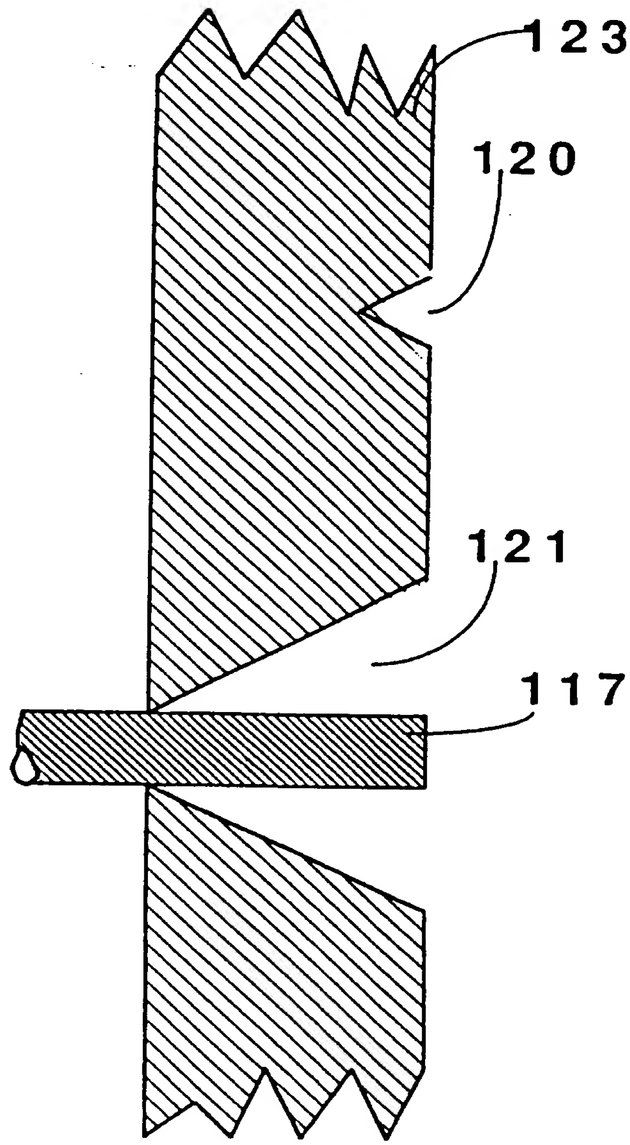

FIG. 62

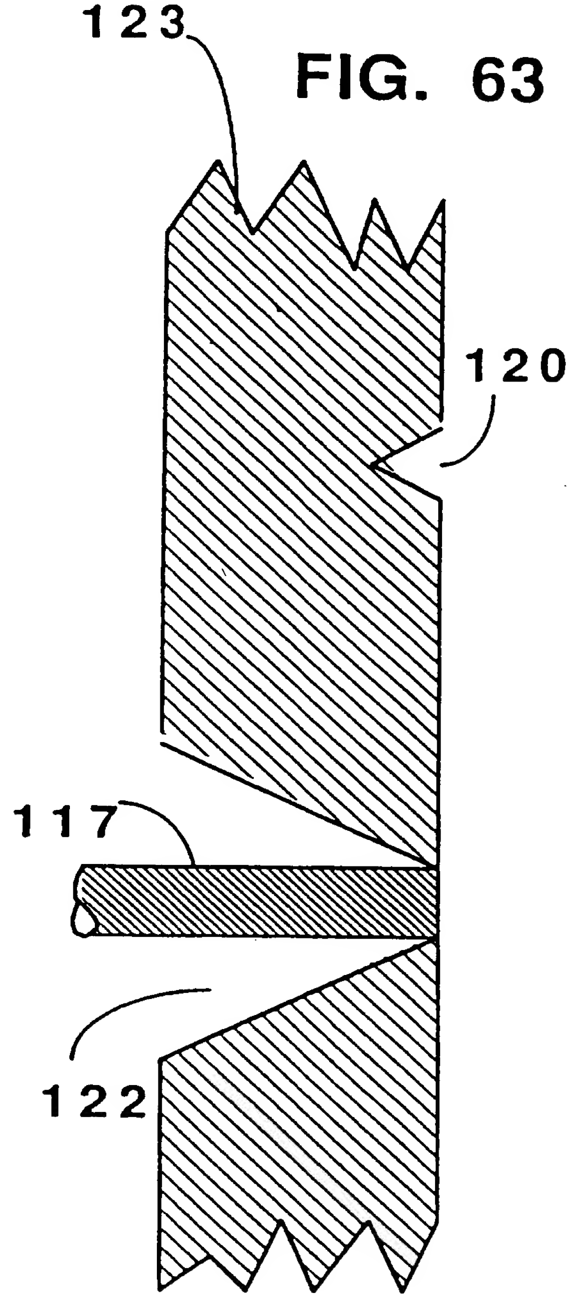

FIG. 63

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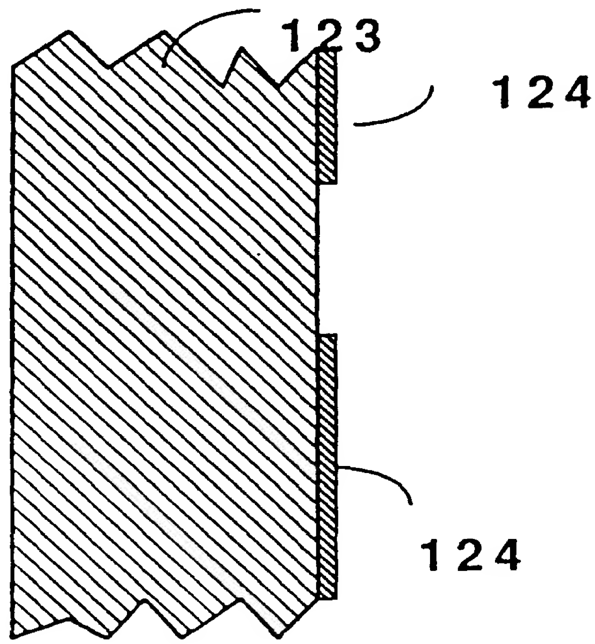

FIG. 64

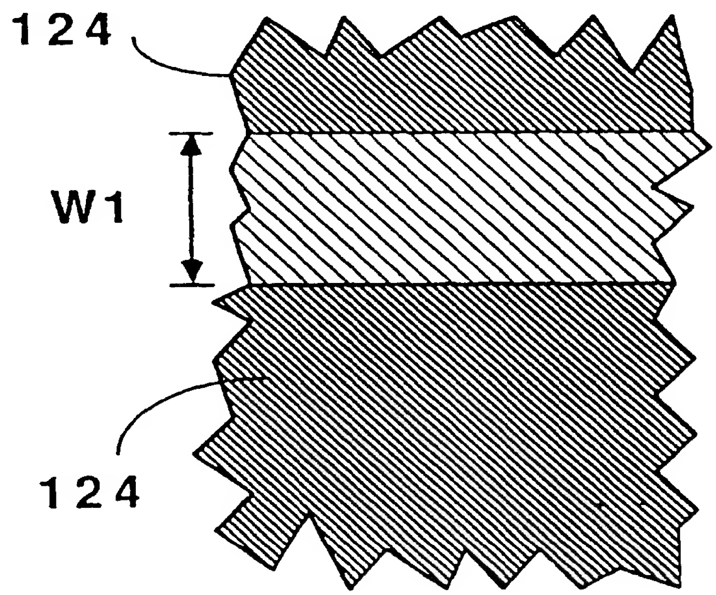

FIG. 65

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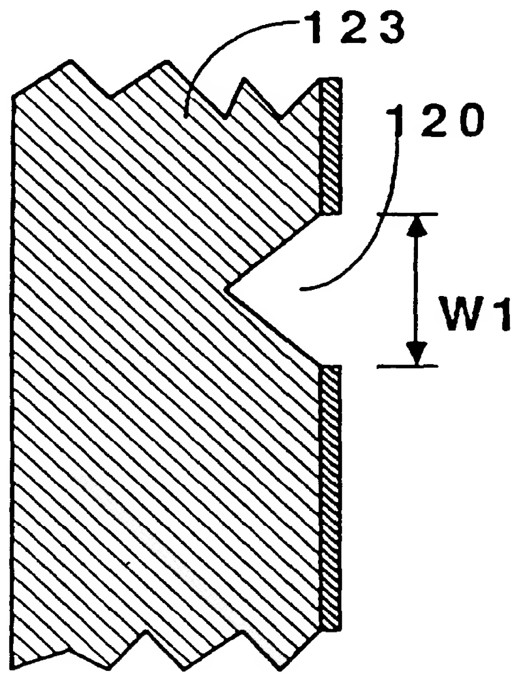


FIG. 66

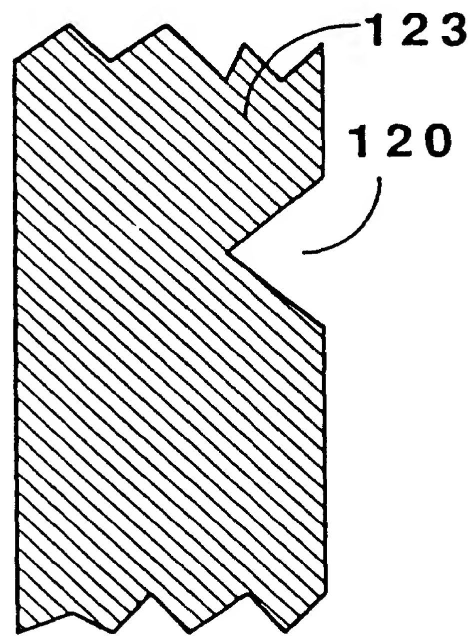


FIG. 67

FIG. 68

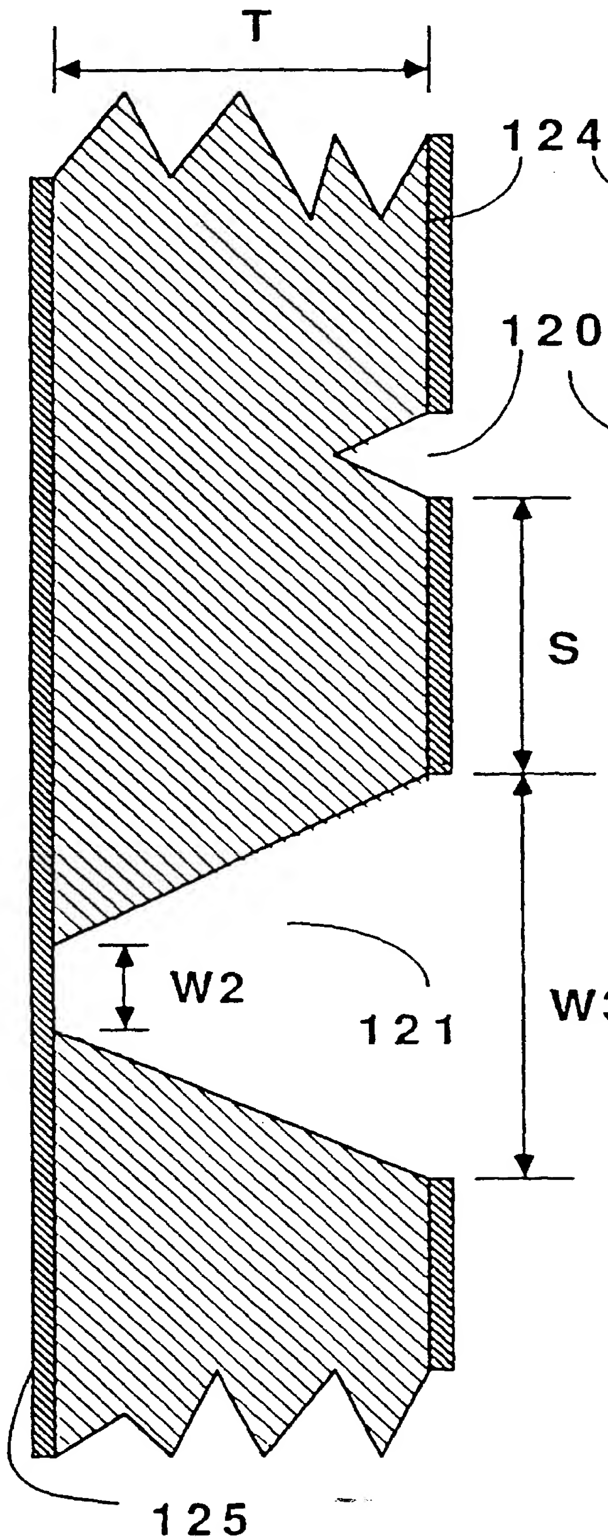
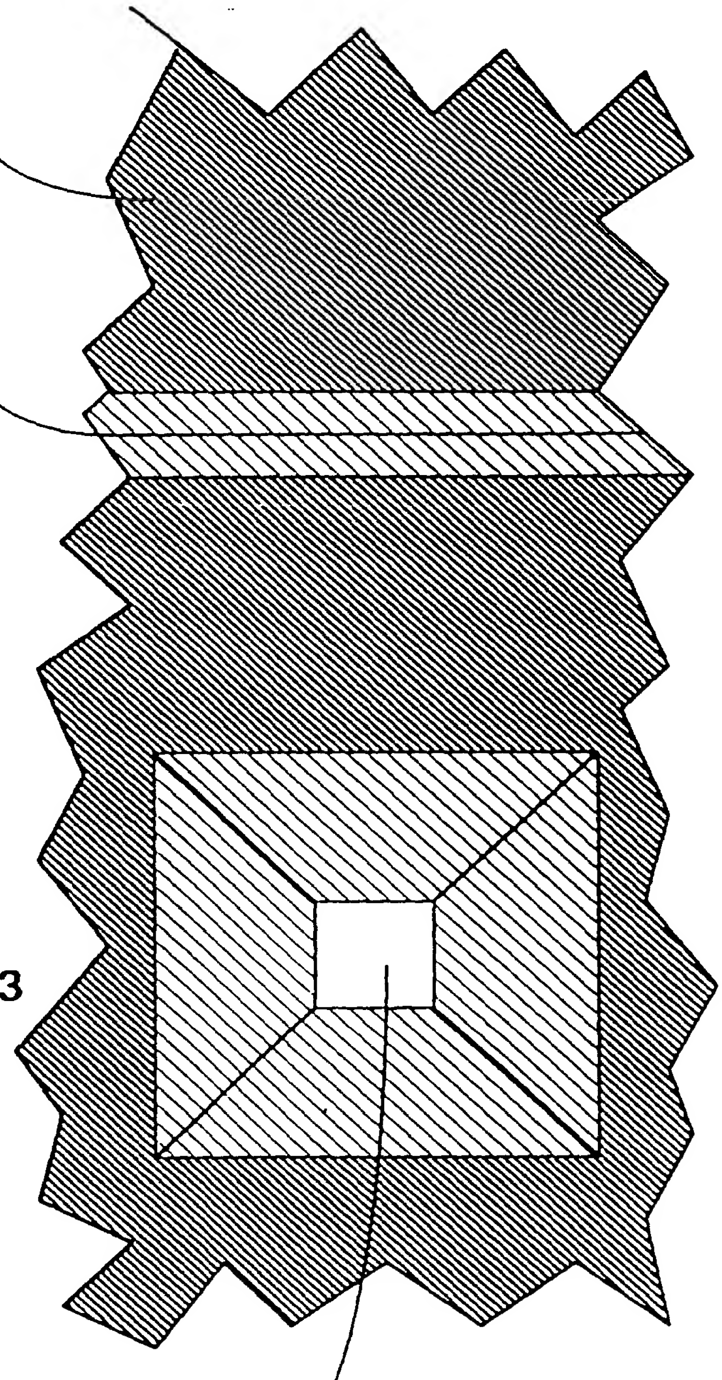


FIG. 69



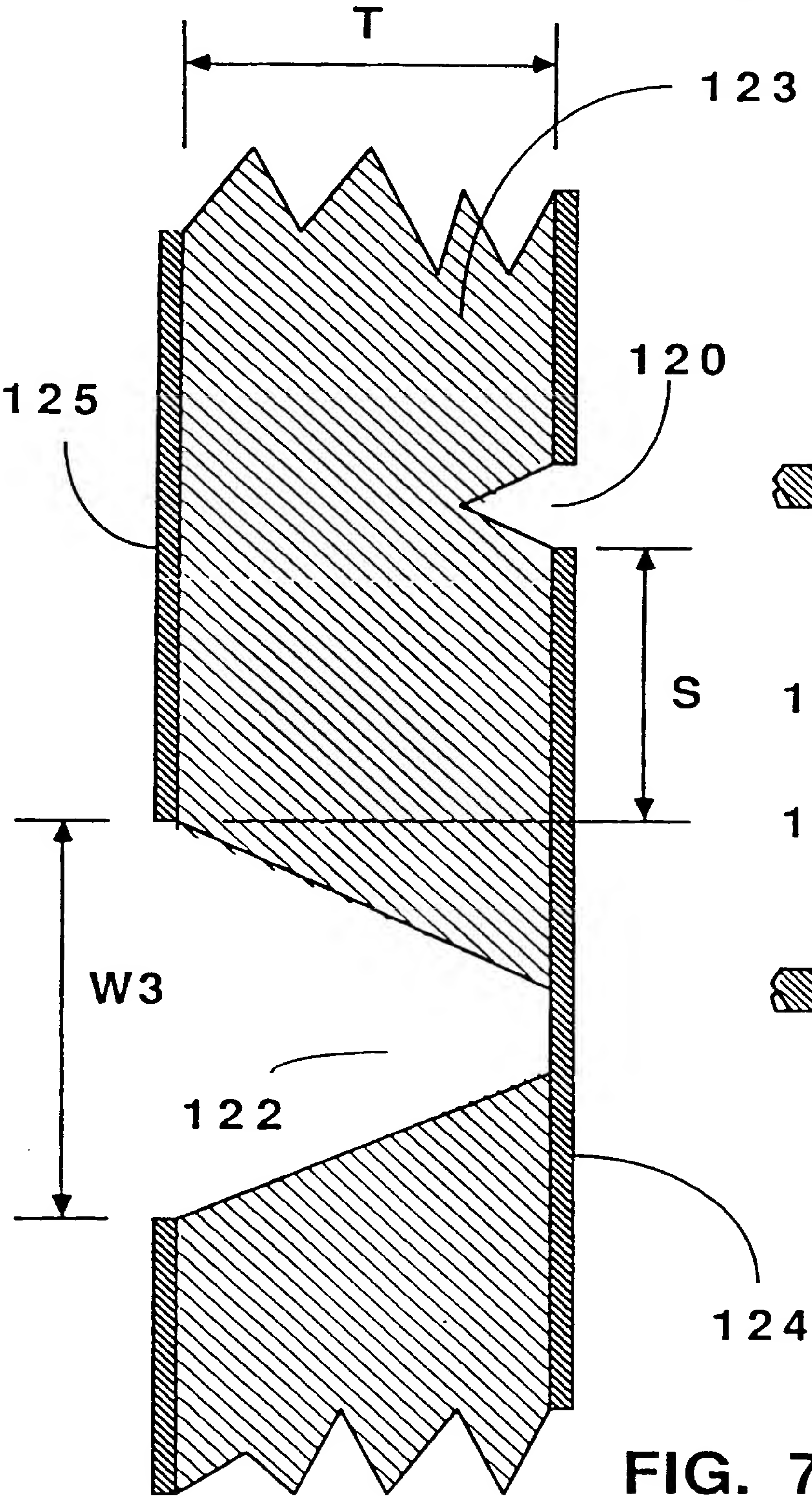


FIG. 70

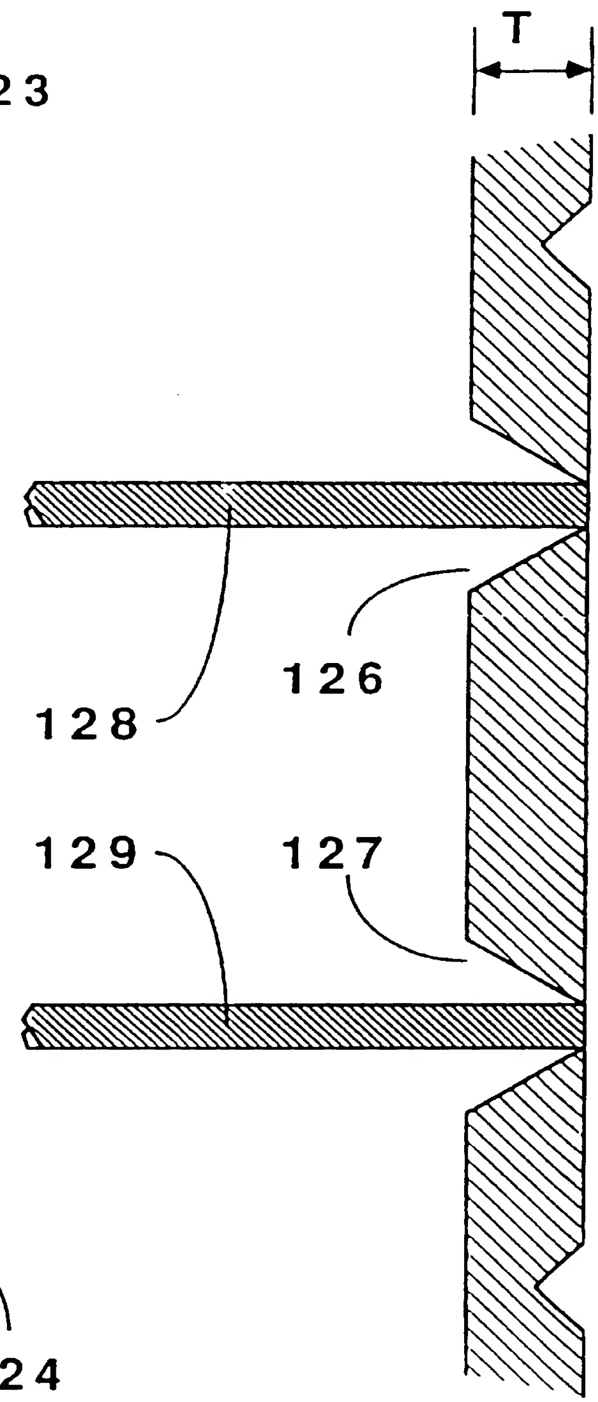


FIG. 71

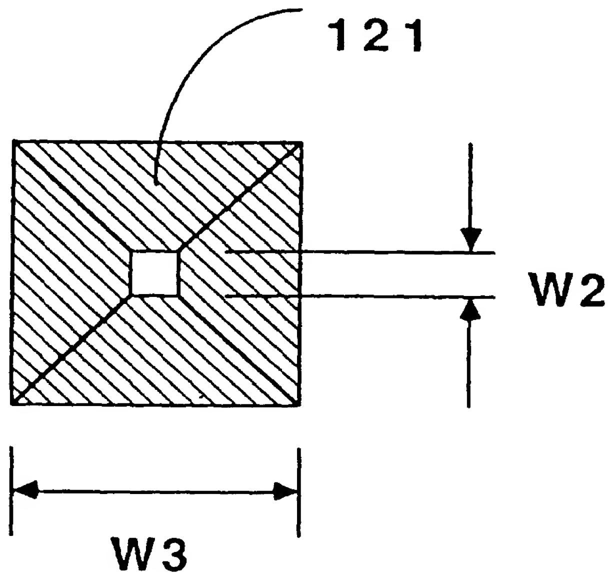


FIG. 72

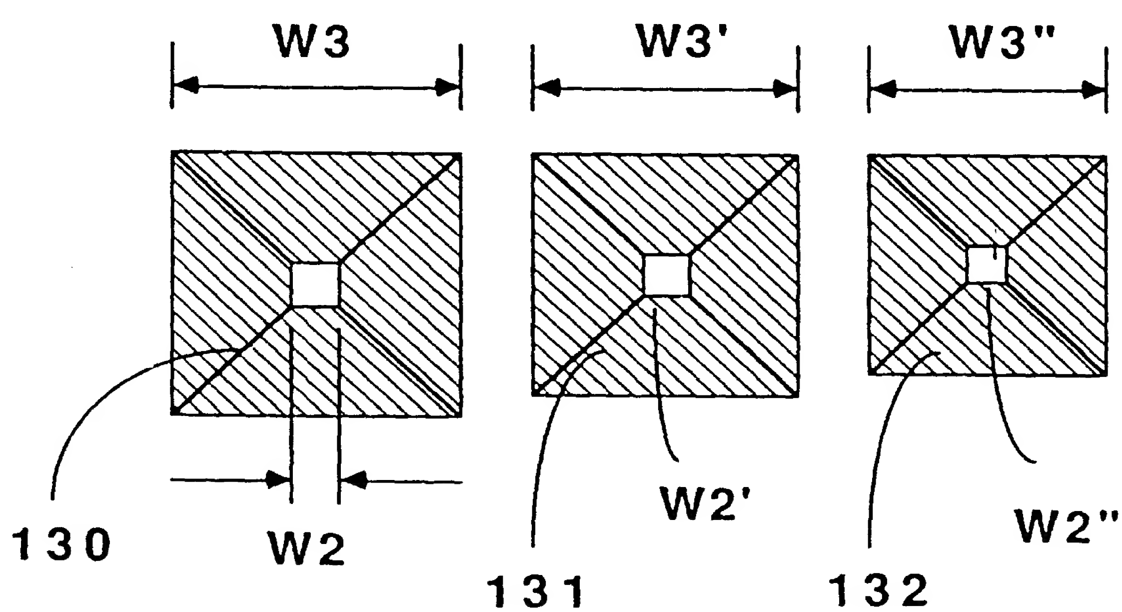
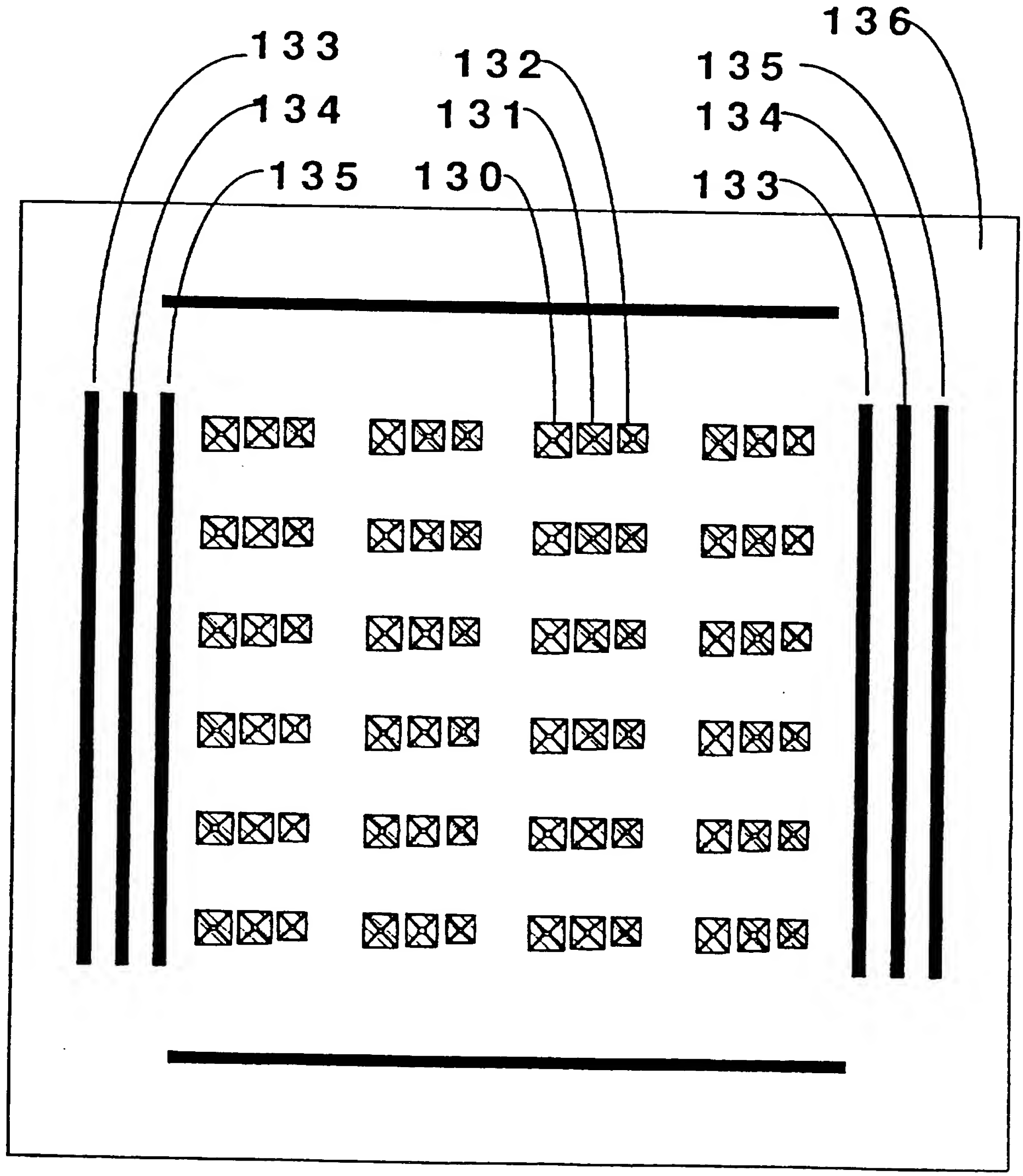


FIG. 73

FIG. 74



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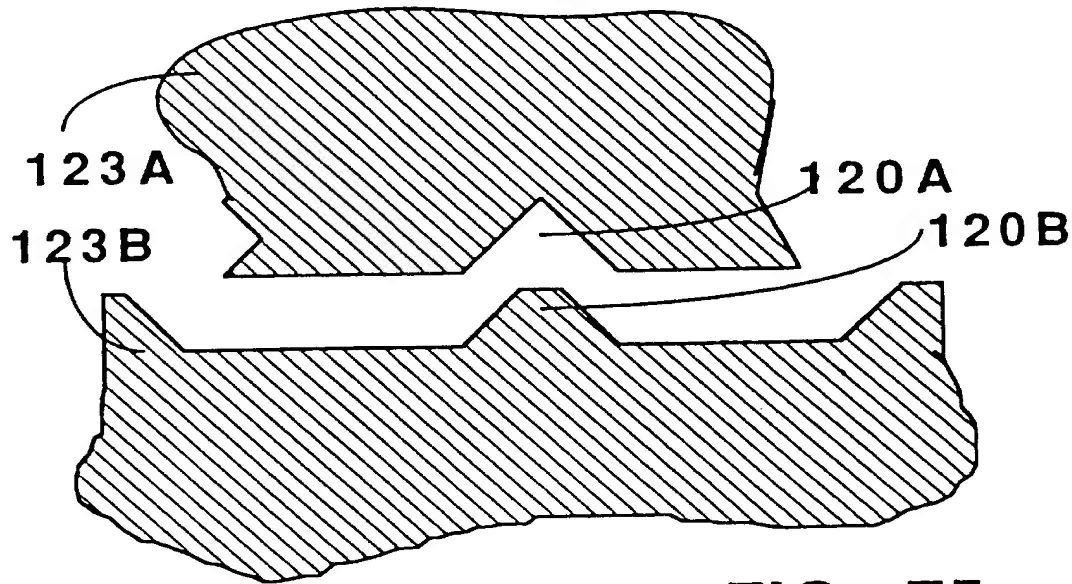


FIG. 75

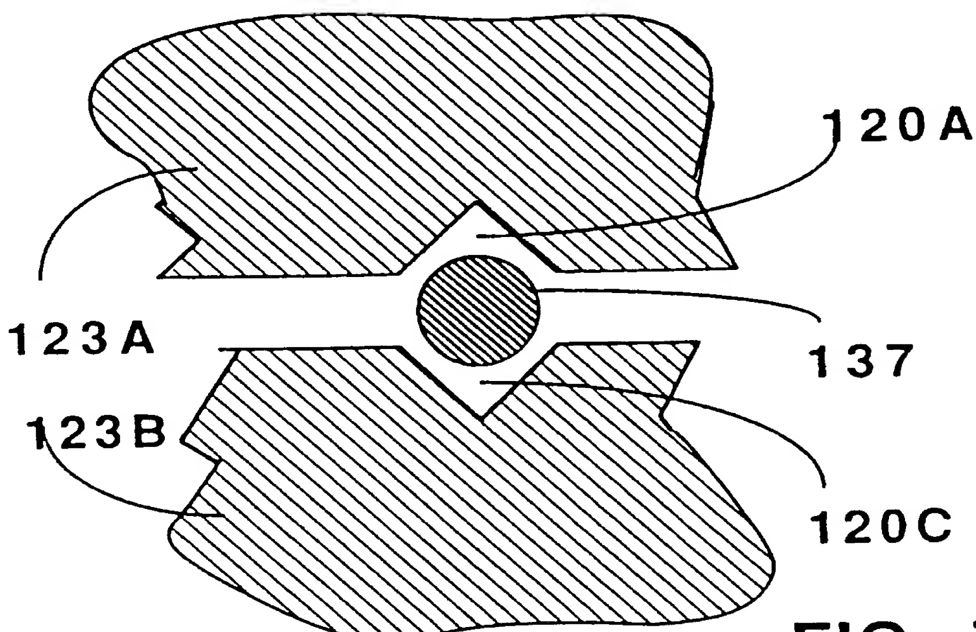


FIG. 76

RECTIFIED SHEET (RULE 91)

FIG. 77

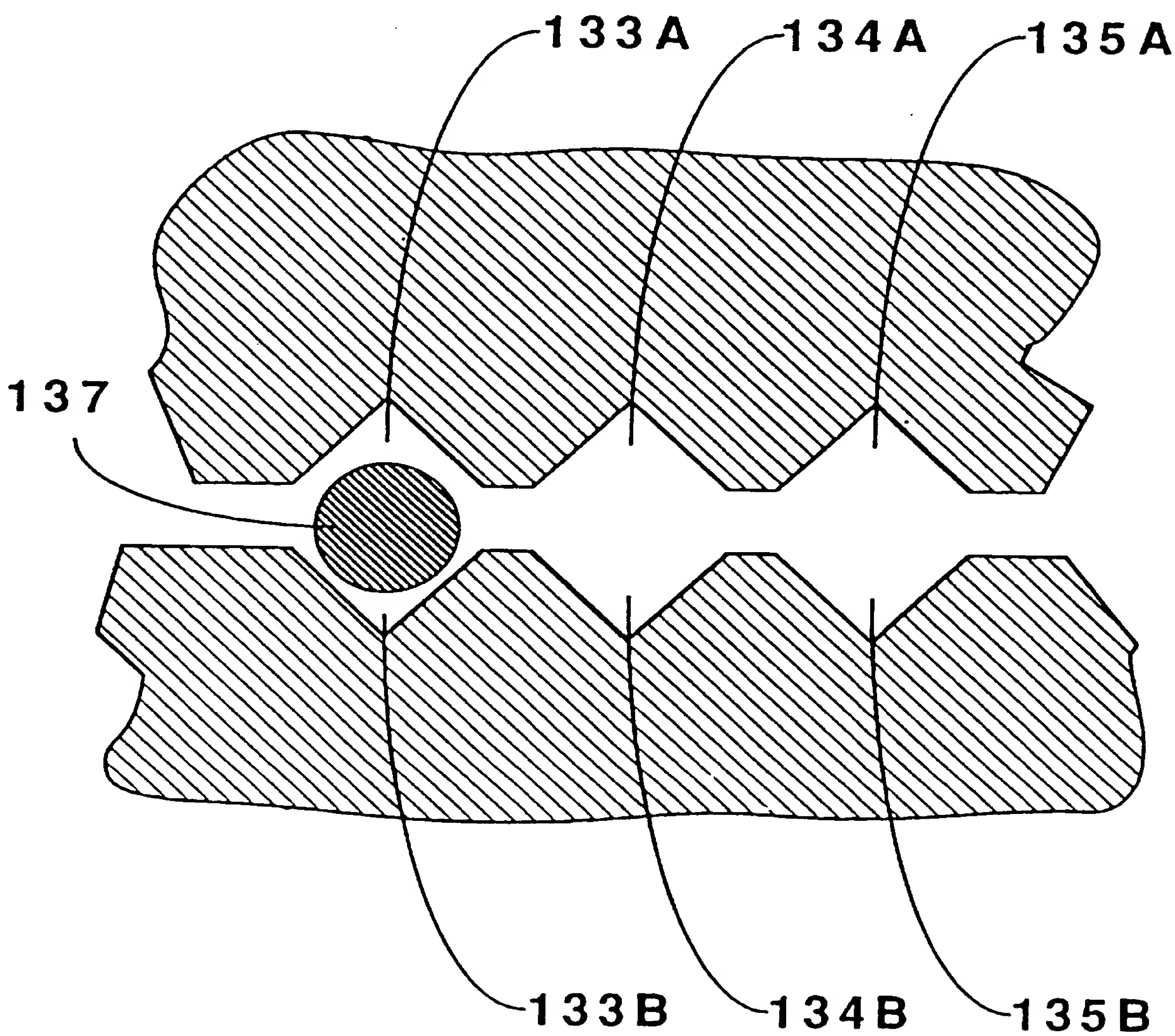
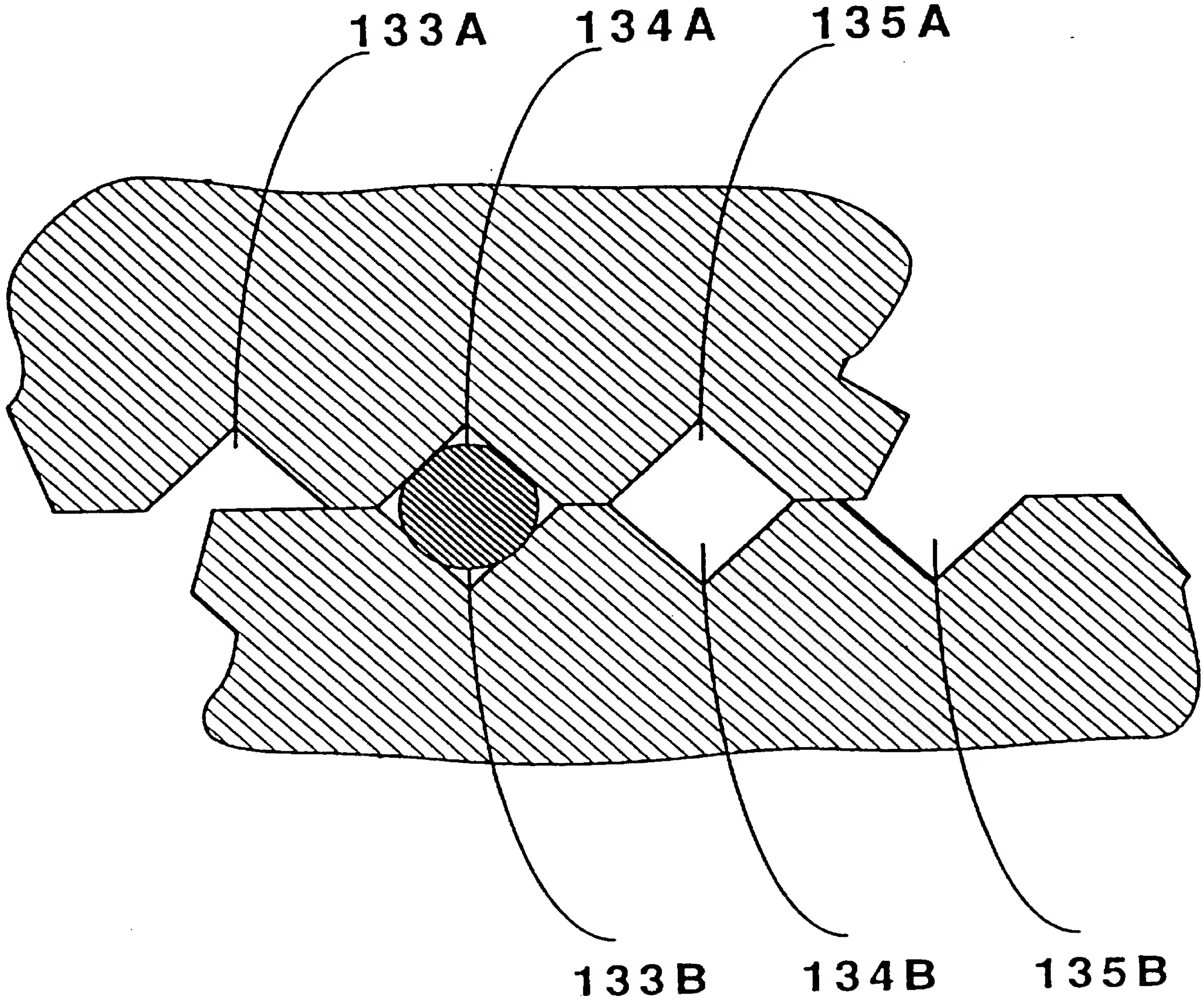


FIG. 78



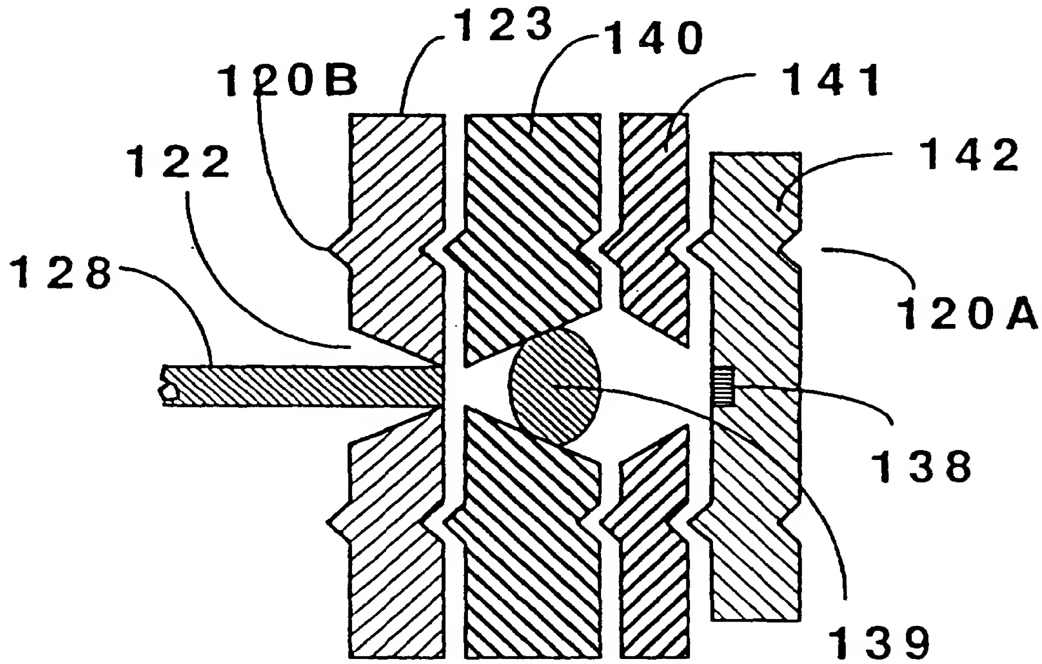

123
140
120B
141
122
142
128
120A
138
139

FIG. 79

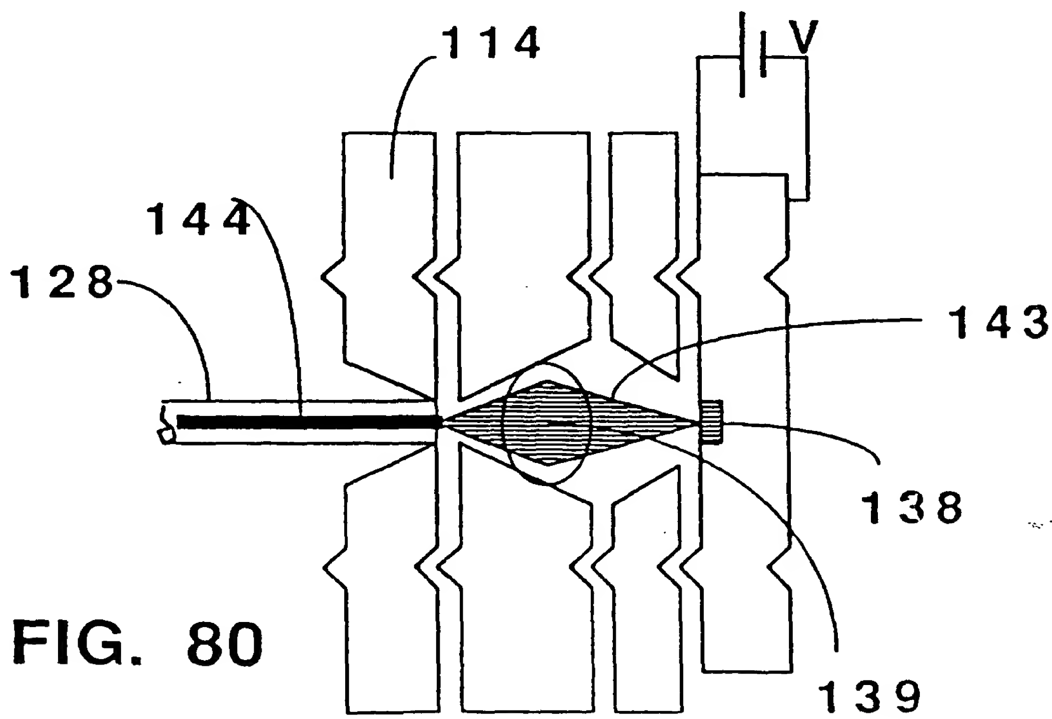

114
V
144
128
143
138
139

FIG. 80

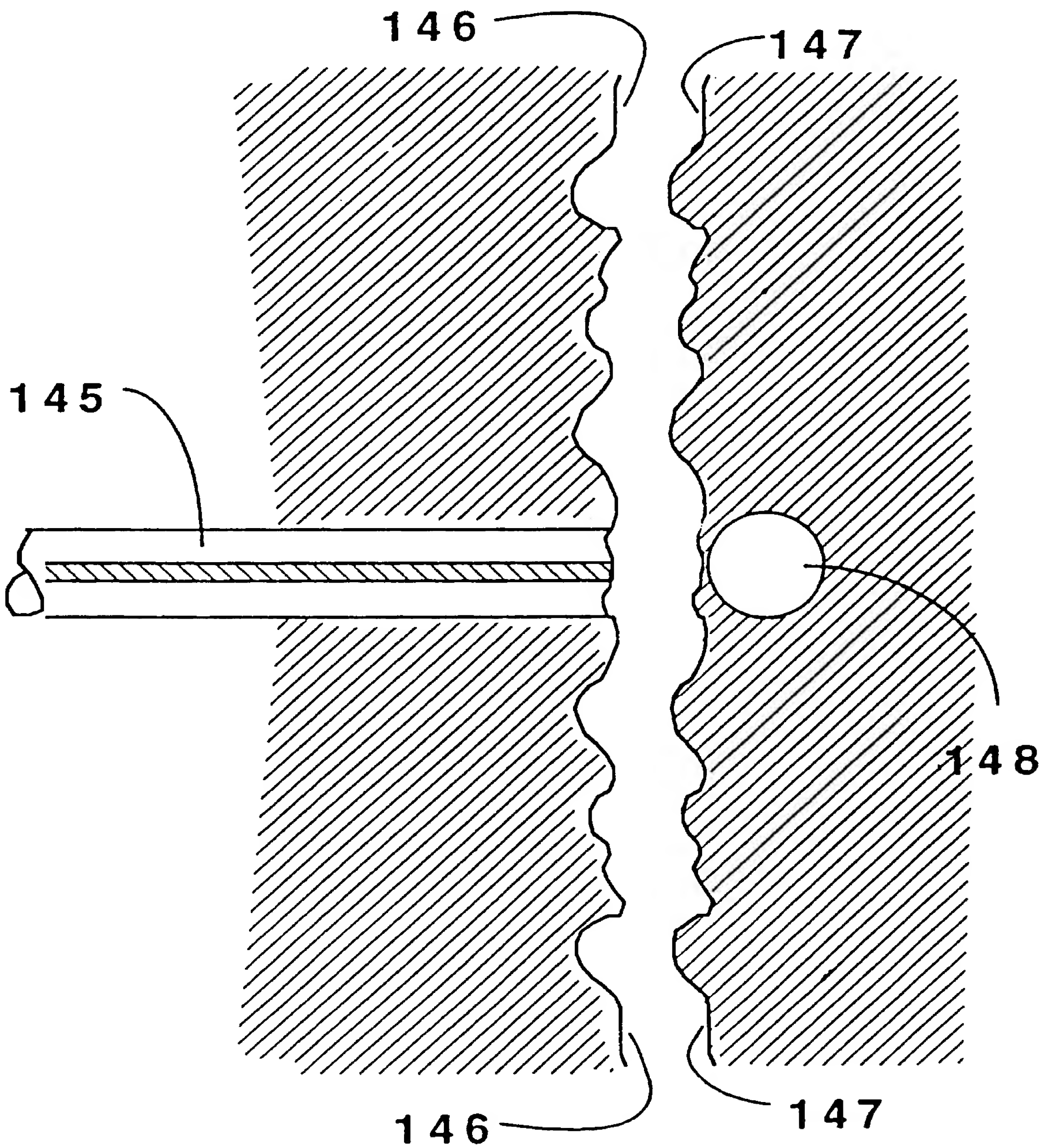


FIG. 81

FIG. 82

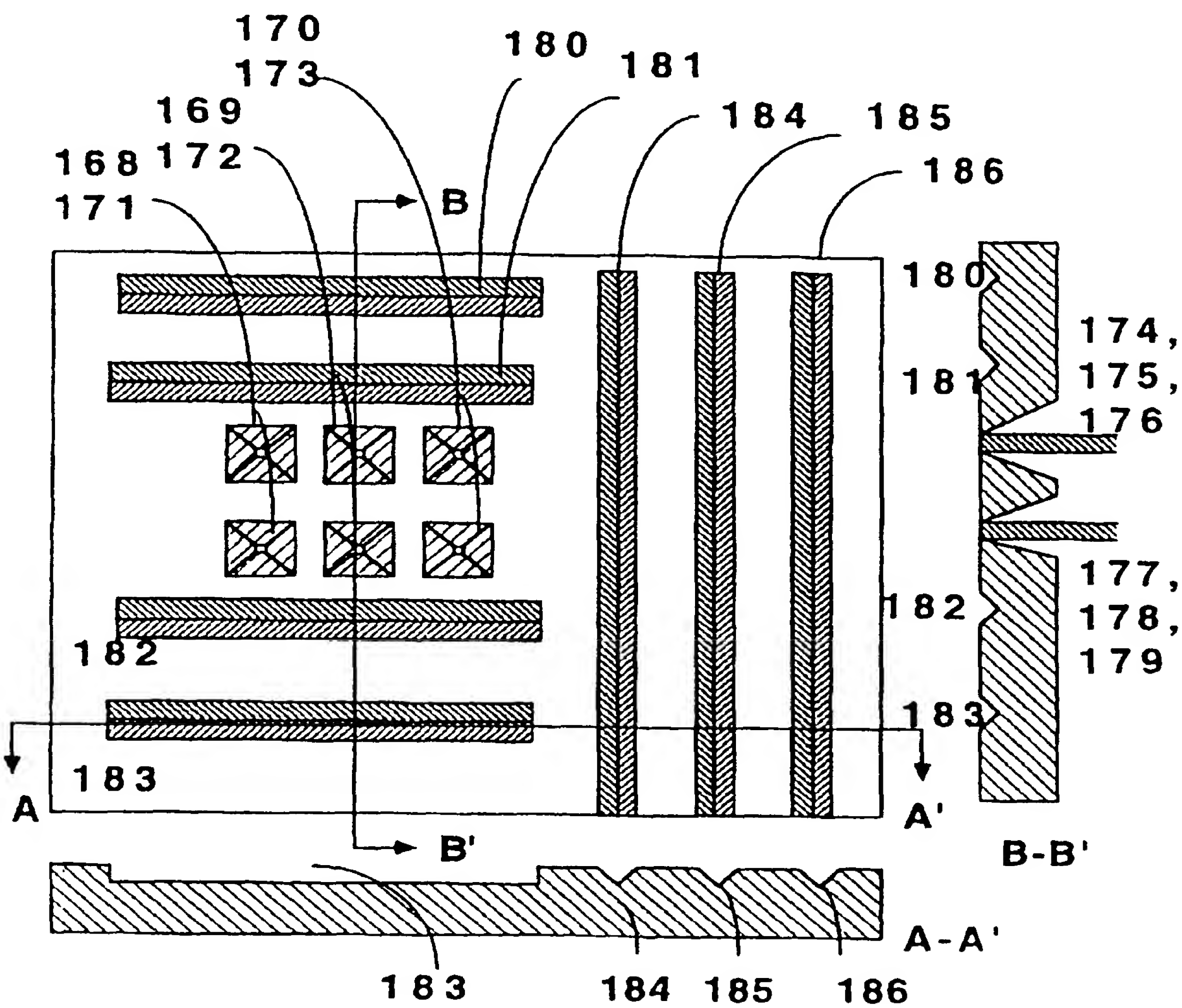

170
173
180
181
169
172
184
185
168
171
186
B
180
174,
175,
176
181
177,
178,
179
182
182
183
183
A
A'
B'
B-B'
A-A'
183
184
185
186

FIG. 83

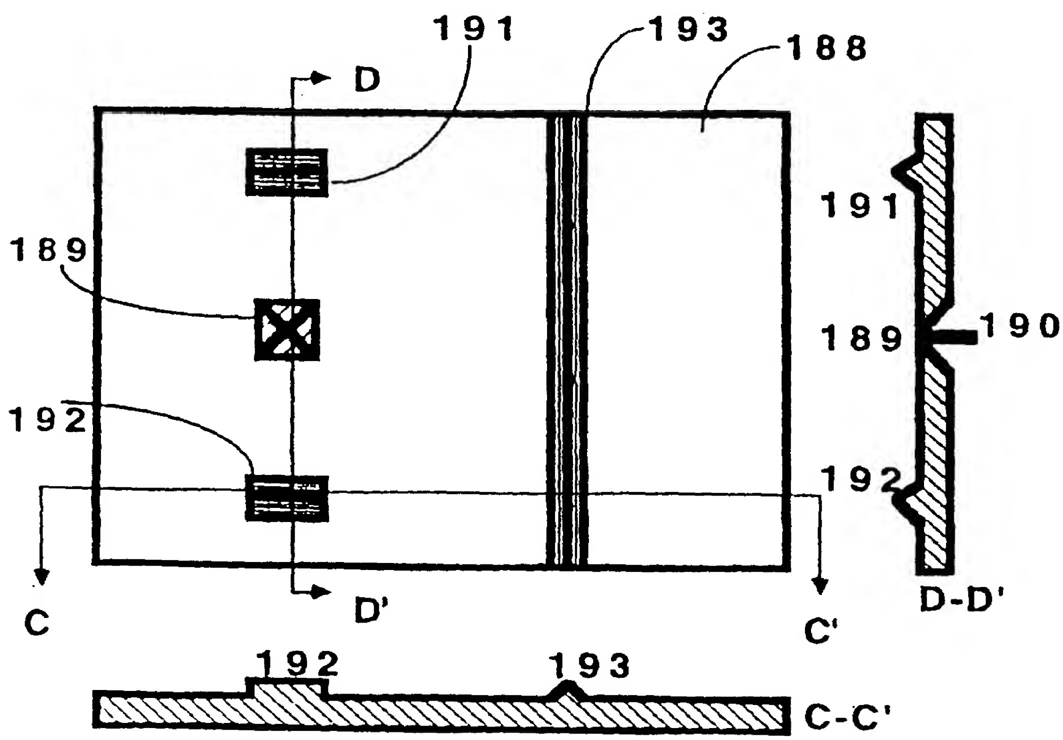
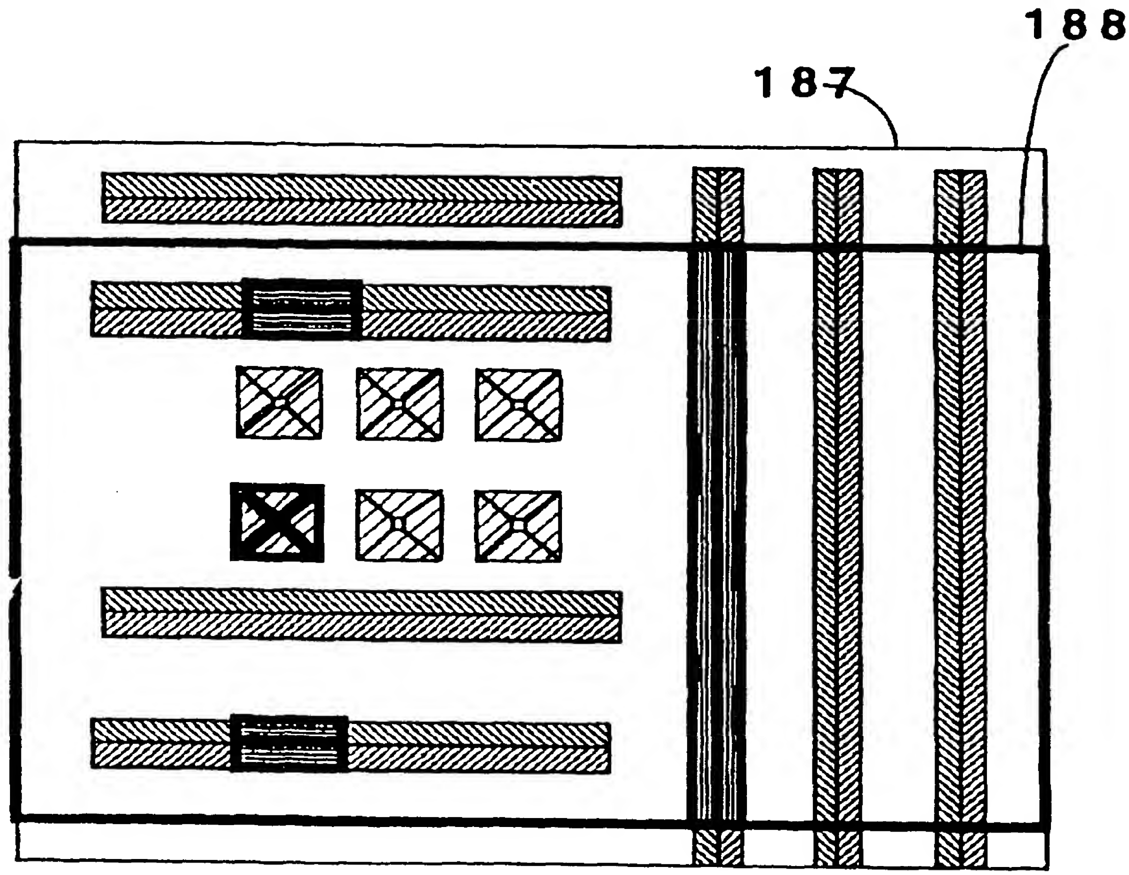


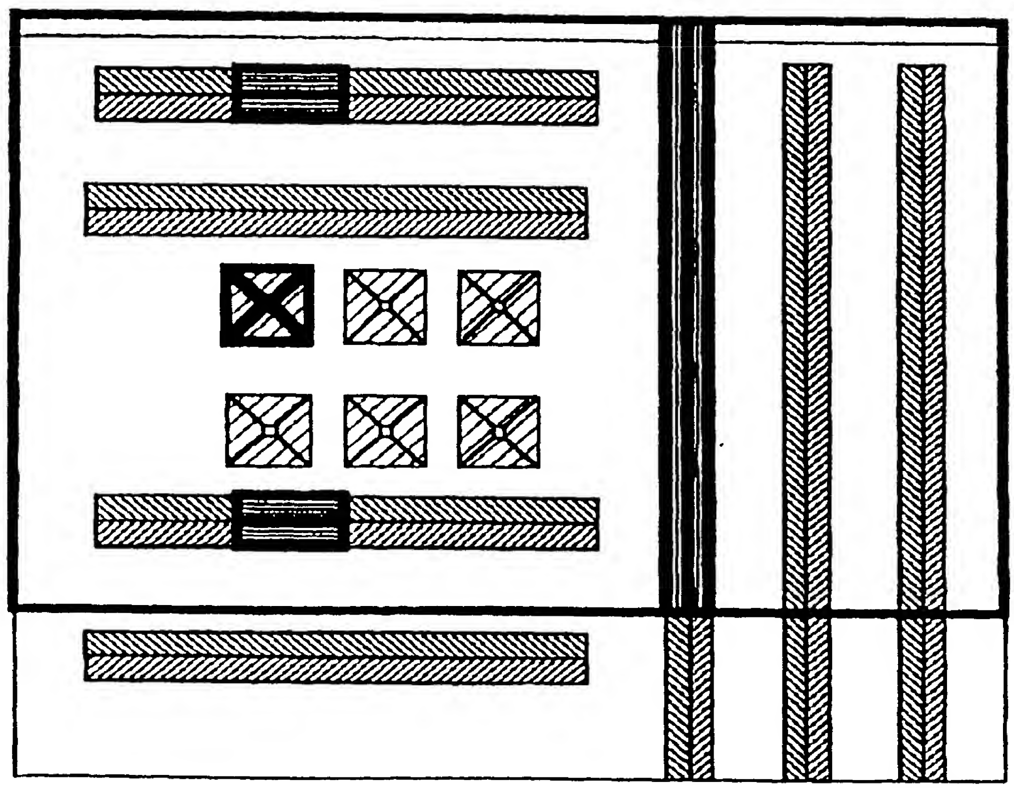
FIG. 84



S.K.Sheem

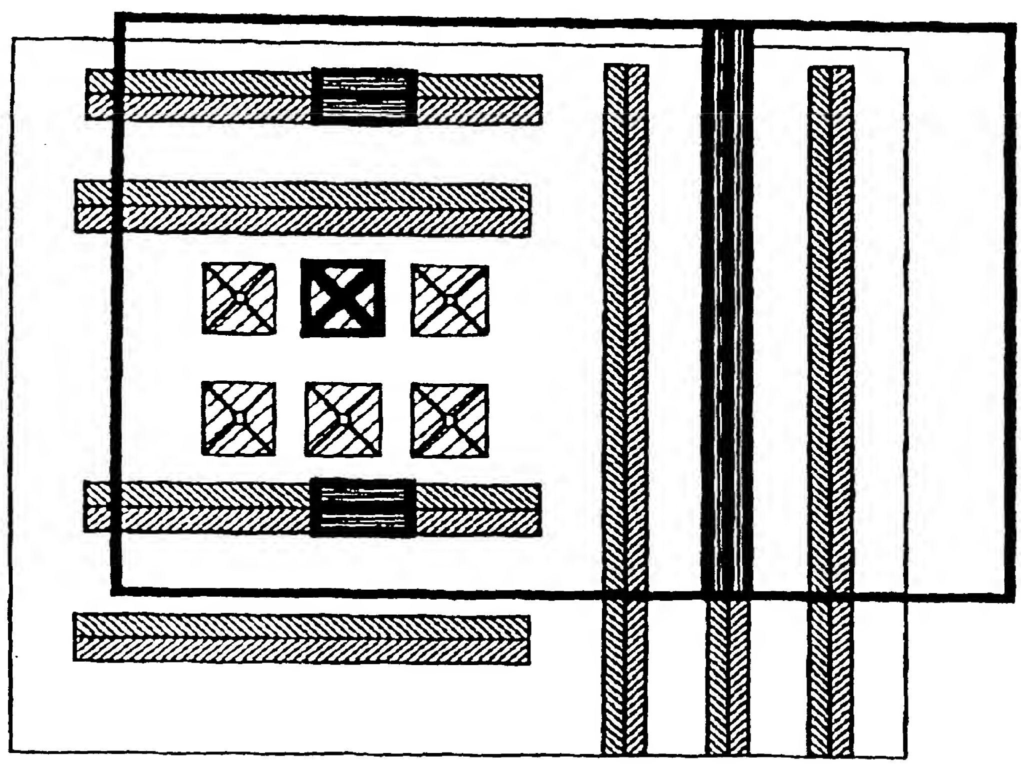
RECTIFIED SHEET (RULE 91)

FIG. 85



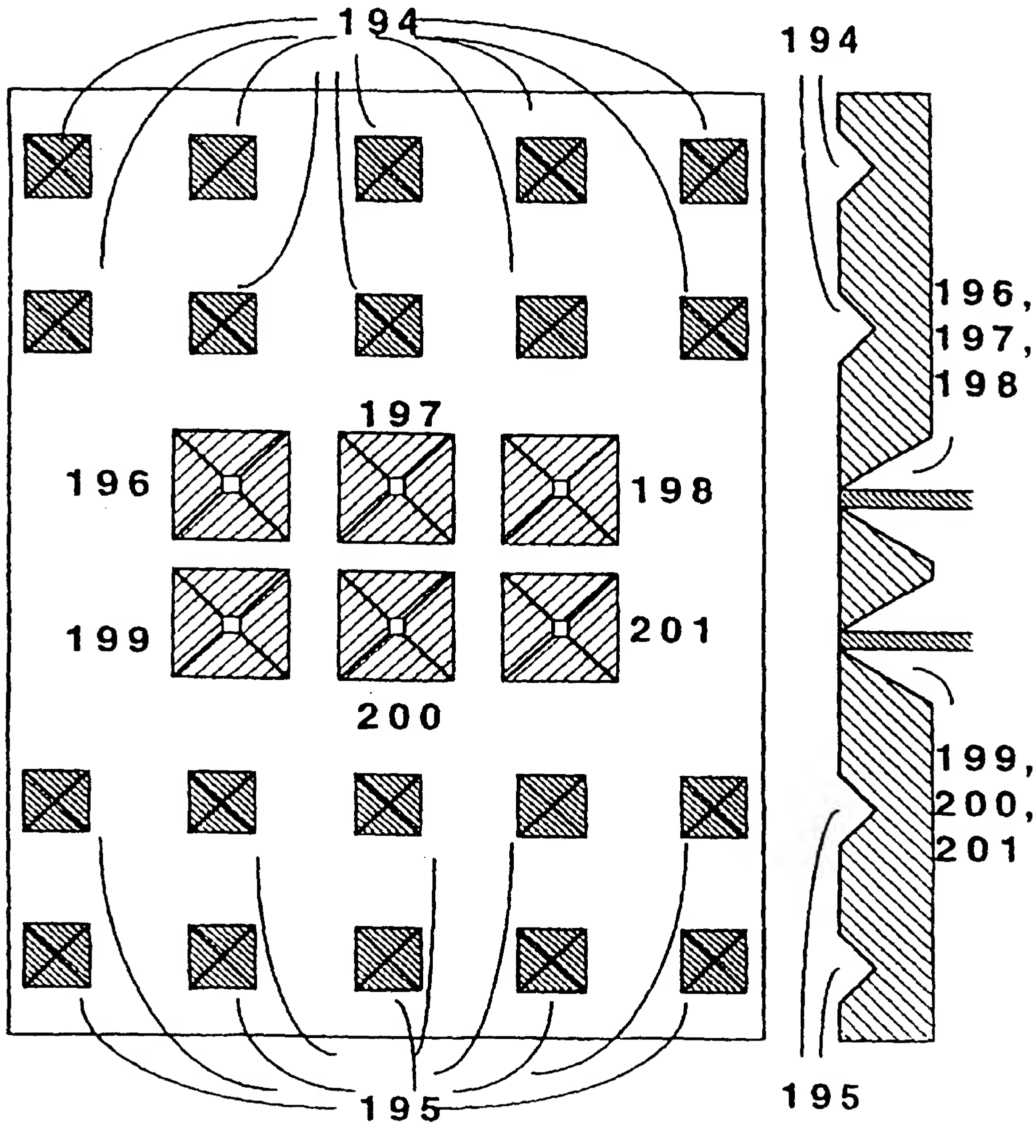
S.K.Sheem

FIG. 86



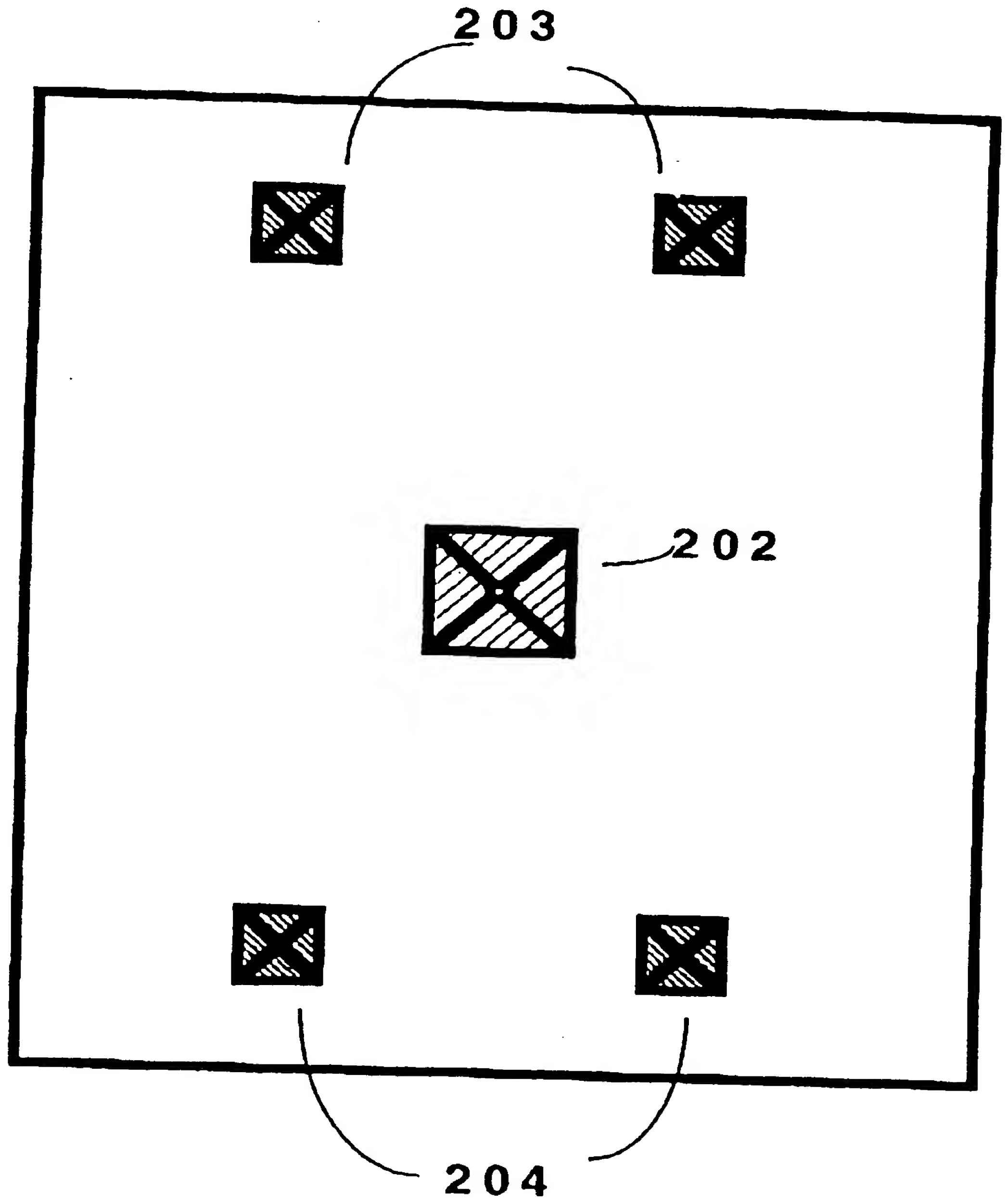
S.K.Sheem

FIG. 87



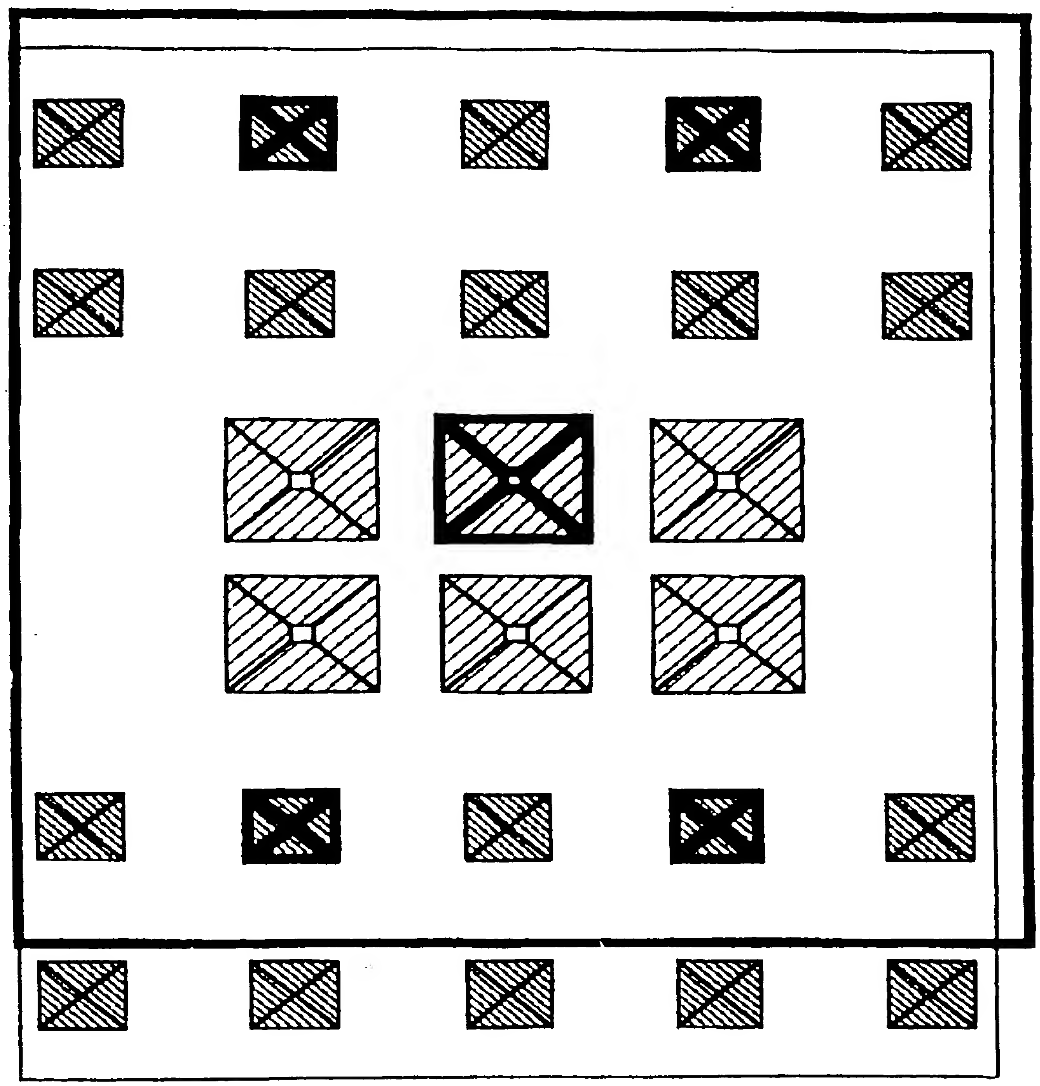
RECTIFIED SHEET (RULE 91)

FIG. 88



S.K.Sheem

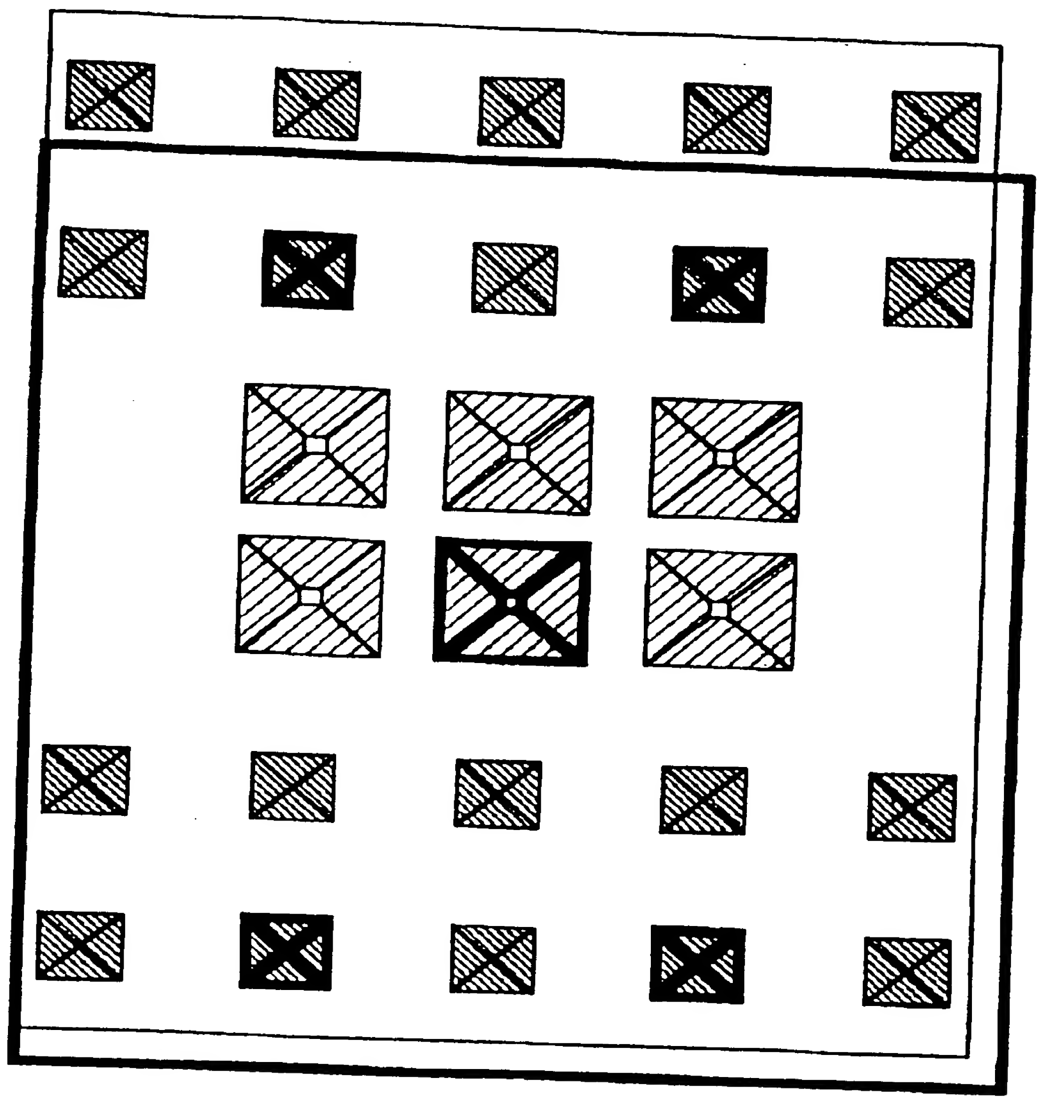
FIG. 89



S.K.Sheem

RECTIFIED SHEET (RULE 91)

FIG. 90



S.K.Sheem